ECOSYSTEM MANAGEMENT SHORTCOURSE

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STRIVE FOR ENVIRONMENTAL QUALITY

CONTENTS

ECOSYSTEM COMPLEXITIES

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INTRODUCTION

The purpose of this presentation is 1) to briefly discuss the nature of ecosystems and 2) to provide some indication of their complexity. Ecosystems are ecological systems resulting from the integration of all of the living and non-living factors of the environment. Ecosystems have a structure which is the assemblage of plant and animal communities together with their habitats. This structure is variable in time and space within a given ecosystem. One kind of ecosystem may change gradually into another or boundaries may be sharp and distinct. Different ecosystems are coupled with one another. Any area can be studied as an ecosystem if the boundaries are clearly defined and fluxes measured. The structure of the ecosystem determines its function--what it does, expressed as rate processes. Solar energy enters the biosphere, flows through the various ecosystems and is lost to outer space. Net primary production, herbivory (including plant disease and parasitism), carnivory (including animal disease and parasitism), reduction, comminution and decomposition are pathways of energy flow. Matter is passed through similar pathways but does not leave the biosphere although many compounds are passed from one ecosystem to another. Thus, matter is cycled while energy flows. Both structure and function are subject to dynamic change which may be non-directional or directional. Directional change may be autogenic, allogenic or induced. Autogenic change is self limiting due to processes of self regulation which bring about stability. Ecosystem structure, function, dynamic change and self-regulatory mechanisms determine 1) kinds of ecosystems, 2) potential human uses, 3) the response of the ecosystem to these uses and 4) the characteristics of wise management. In this paper special consideration is given to structure and function with special reference to primary producers.

ECOSYSTEM STRUCTURE

The different subsystems of ecosystem structure may be classified as site constants, driving variables and state variables.

Site Constants

Site constants are those components of the environment that change very slowly such as climate, geological materials and available organisms. Important elements of climate (the long term average of weather) include intensity of solar radiation in different wave lengths, temperature, precipitation, atmospheric humidity, wind, potential evapotranspiration and cloud-to-ground lightning. These elements are interrelated and are

variable in time on daily, seasonal, annual, and longer time periods. Cyclical variation is common. They are variable in space horizontally and vertically.

Geological materials include the parent material, relief and ground water. Parent material is the material from which soil is formed and may be considered to include the soil matrix which has accumulated at any specific time. Parent materials are variable in physical and chemical composition and consequently in color, resistance to weathering and rate of soil formation, thus resulting in differences in physical and chemical properties of the soil. Relief is the configuration of the parent material and is continually modified by geological processes. Ground water is largely a function of relief and climate. The geological materials are variable in geological time and many of them in recent time. They are markedly heterogeneous in space. Regional climate and relief interact to produce local climates.

The available organisms include the flora and the fauna and the microflora and microfauna which are available to populate an ecosystem. These organisms have been molded by climate and geological materials through time resulting in genetic variability in form and function. Both specific and infraspecific genetic variation are almost always present. The site constants--climate, geological materials, and available organisms--interacting through time determine the nature of the ecosystem, its average expression.

Driving Variables

The driving variables are the elements of weather, the instantaneous expression of climate. These forces drive the rate processes that are involved in ecosystem function. They are responsible for the variation in the state variables. The site constants and the driving variables are the controlling factors of the ecosystem.

State Variables

The state variables are determined by the site constants interacting through time. They are the dependent factors of the ecosystem and include the microclimate, soil, primary producers and organisms of the grazing food web and the detrital food web.

Microclimate

The microclimate (and its instantaneous expression, microweather) is a characteristic of the habitat of a particular population of organisms and is the result of the interaction of the local climate (and weather) and the communities of living things. The vegetation is especially important in differentiating different microclimates. Microclimates are variable in time and in space, both horizontally and vertically. The teleoclimate is the climate at the surface of an

organism where exchanges of energy and gases occur.

Soil

The soil subsystem includes the slowly changing soil matrix. These slowly changing characteristics can be considered as site constants for most planning periods. Among these parameters are topography (including aspect, inclination and slope position), microrelief, potential rooting depth, depth to lime, soil development, texture, structure, water retention characteristics, pH, cation exchange capacity, and contents of organic matter, nitrogen, phosphorus, calcium and other elements. The soil subsystem also includes highly dynamic state variables such as water, chemical ions of the soil solution, and metabolic products of microorganisms, plants and animals. These dynamic parameters are legion. The values of available water, ammonia, nitrate and bicarbonate phosphorus are especially important in ecosystem function.

Biocoenose

The communities of living things that exist as dependent factors of the ecosystem integrated with the microclimate and the soil subsystem are known as the biocoenose. These organisms may be classified as primary producers, organisms of the grazing food web (herbivores, multivores, carnivores, and parasites) and organisms of the detrital food web (reducers, microfloral grazers, carnivores, micropredators, parasites, decomposers and transformers). A compartmental diagram of the biocoenose with flows indicated between compartments is shown in figure 1. Compartments are similar above and below ground, although kinds and proportions of organisms are widely different. The grazing and detrital food webs are partially linked with some organisms functioning in both webs.

Taxonomic diversity in the biocoenose is so great that it is often desirable to classify organisms according to their ecological characteristics. Structural attributes of the biocoenose are determined by the site constants and driving variables as modified by human use.

The biomass of different compartments (time-weighted growing season means, g/ha ovendry) of two mixed prairie ecosystems, one disturbed and the other relatively undisturbed by recent large animal grazing are shown in figure 2. A log scale is used to permit graphical representation. The figures are untransformed values.

Primary producers

Communities of green plants, both cryptogams (bryoids, such as mosses, liverworts, some algae, lichens, filmy ferns and mossy lycopods) and phanerogams (trees, vines, shrubs, semi-shrubs, graminoids, forbs and succulents) are the primary producers. As many as fifty species of these different life forms are not uncommon in an ecosystem although the greater part of the biomass is

usually concentrated in less than ten and often fewer than five species.

Genetics. The genetics of these organisms determines their response to their multifactor environment including human manipulation. Their genetic makeup differs by family, subfamily, tribe, genera, subgenera, species, ecotype, and biotype. Some important characteristics are common at the family, subfamily, or tribal level. For example, all of the grasses studied in the subfamily, Festucoideae are cool season, have a C_3 photosynthetic pathway and store fructosans as reserve carbohydrates, while the members of the Panicoideae (except for one subgenera) and the Eragrostoideae are warm season, have a C_4 photosynthetic pathway and store starch.

Both intergeneric and interspecific hybridization, often with development of polyploidy (multiple chromosome complements) have been important in grasses. About 70% of the known species of wild grasses are of polyploid origin. Ingeneral, polyploids have a wider range of tolerance for extreme environmental conditions than their diploid ancestors and thus have a wider geographical range. Levels of polyploidy range from diploid to octoploid or higher. Irregular chromosome numbers are also common. These differences appear to be related to ecological adaptation.

Breeding systems also influence genetic variability. Most plant taxa are cross fertilized but some are self-fertilized and some produce seed with genetic contribution from only one parent (process of apomixis). Taxa that reproduce only apomictically have no capacity for adaptive change to cope with a changing environment. However, some taxa reproduce either sexually or apomictically, depending on environmental conditions (facultative apomixis). Apomixis and/or strong vegetative reproduction is especially common in polyploids. Polyploid grasses of hybrid origin that reproduce apomictically as well as sexually have a tremendous range of genetic variability within a single individual which can be transmitted essentially unchanged from generation to generation permitting excellent adaptation to a stable environment. Furthermore, concurrent sexual reproduction provides excellent adaptation to changing environments. Cross-fertilized taxa with strong vegetative reproduction, weak seed production, and poor seedling vigor may also provide adaptation to both stable and rapidly changing environments. A knowledge of the cytogenetics of the major primary producers is often necessary in order to understand the reaction of the plant community to environmental change or human manipulation and to understand the differences in function between different ecosystems.

In response to the selection pressure of different environmental factors acting simultaneously upon genetic variability in both diploid and polyploid plant populations reproducing sexually (or by facultative apomixis) gene frequency is altered. If reproductive isolation occurs, these differences accumulate quickly resulting infraspecific genetic variation in species with wide geographical ranges, continuous genetic variation (ecoclines) will usually be found where environmental gradients show continuous variation. If environmental gradients are steep or if a species has a discontinuous range, ecological races or ecotypes are likely to be found. Ecoclinal variation may be observed within ecological races patterned

along gradients of smoothly varying climatic factors. Local ecotypic variation also may occur within clinal variation or local small scale ecoclines may be encountered. Thus, there is genetic adaptation to a multifactor environment in which the environmental factors may show discontinuous variation or continuous variation with steep or shallow gradients. Within the population genetic variability is determined by the genetic structure of individuals and the method of reproduction. Most characters that distinguish ecological races have multiple gene inheritance. Some infraspecific genetic variants can be recognized on the basis of morphological characters but some may be distinguished only on the basis of their physiology. Genetic variants of the same grass species may be adapted to different site constants (such as photoperiod, temperature regime, soil water regime, and soil texture) or even management factors such as grazing intensity. Thus, the population genetics of the primary producer community must be understood in order to understand ecosystem function or response to management.

Age components. Primary producers have several components which may be classified as supporting structures, new growth or dead components. Supporting structure may be woody or perennial live material. New growth may be supporting tissue, vegetative tissue (such as leaves, stems, twigs, or roots), reproductive tissue (such as fruits, rhizomes and stolons) or storage tissue. New growth passes through successive stages of maturity, becomes senescent and dies. Dead components may be recognized as recent dead, old dead, fresh mulch, humic mulch and soil organic matter based on the extent of decomposition and fragmentation. The proportion of these components is ultimately dependent on the site constants and driving variables, but is directly dependent on the genetics of the primary producers, the driving variables and the degree of herbivory. The amount and proportion of these components determines the relative importance of the grazing and the detrital food webs, the relative proportion of organisms in each and the nutritional status of grazing herbivores.

Periodicity, stratification and diversity. Site constants interacting through time appear to select plant communities that maximize biomass accumulation within the constraints of survival. Where the resources of the site exceed the capacity of a single species to exploit them efficiently (such as long, wet, growing seasons with deep fertile soils) a number of plant taxa are usually important in the community, resulting in periodicity of growth and flowering, stratification above and below ground and high diversity indices. Lack of periodicity and stratification with very low diversity results from the presence of a highly competitive species which is able to exploit the resources of the site. Soils in which nutrient release is slow must select either a plant community that grows slowly or a highly diverse community in which peak nutrient demands are made by different species at different times. The latter community accumulates the greater biomass. Overgrazing usually disrupts periodicity and stratification and reduces diversity.

Spatial pattern. Morphological, sociological and environmental patterns occur in plant communities. Species interactions produce sociological pattern. Allelochemicals released by one plant and affecting the growth and development of others are important determinants of this kind of pattern. Environmental patterns are due to the interaction of the individual plant with gradients of site constants, biotic influences and influences of man. Patterning is usually along multiple gradients and occurs on macro-, meso- and micro-scales.

Grazing and detrital food webs

The herbivores are the grazers or chewers (including the stemborers), sap suckers (including the rasping suckers), seed consumers and nectar feeders. The grazers and chewers include the large ungulates, lagomorphs, small mammals and a variety of chewing and boring insects in immature or adult stages. Some of the small mammals and arthropods operate below as well as above ground. The sapsuckers are mainly the sucking insects and the plant parasitic nematodes. Seed consumers occur among small mammals, insects and birds. Nectar feeders are birds and insects. A few large mammal and a large number of small mammal and insect taxa consume both plant and animal material and are classified as multivores. Carnivores include the large carnivores, the tiny shrews, predatory and parasitic insects, spiders, mites and nematodes. Some of these carnivores also feed on the organisms of the detrital food web.

Large scavengers are important in the detrital food web, of course, but likewise a large number of invertebrate taxa are important in the reduction and comminution of dead organic matter (reducers). These include earthworms, mollusks, isopods, diplopods, certain dipteran larvae, some beetles, ants and mites. Many of these organisms pass large amounts of organic matter through the digestive tract and excrete it in a form easily attacked by decomposing fungi and bacteria. The large biomass of fungi and bacteria is grazed by nematodes, enchytraeds, collembolans, ants, and mites. Each of these organisms has its own parasites and predators. The detrital food web is naturally concentrated where dead organic matter, faces and exudates are concentrated, such as in dead animals mulch, manure, the rhizosphere, and the phyllosphere.

The detrital and grazing food webs are interlocked since many large carnivores are also scavengers and many smaller carnivores consume organisms of both webs. Total biomass of the detrital food web usually exceeds that of the grazing food web. The biomasses and population structures of the communities of the grazing and detrital food webs are the result of the interaction of the site constants through time as influenced by the driving variables directly, and indirectly, through their effect on the primary producers and on other organisms of the two webs. Genetic variability, population structure, niche differentiation and patterns in time and space are important attributes of each taxa in each web.

ECOSYSTEM FUNCTION

Energy Flow

Solar energy entering the biosphere is trapped by green plants

in the process of photosynthesis in the form of three or four carbon compounds which are changed to six carbon sugars and moved to various parts of the plant where they are combined with minerals and water from the soil into new tissue used in respiration, transmuted for storage, or combined into various chemicals which are used in the plant, excreted, or isolated. The catabolic reactions of plant respiration provide energy and carbon compounds for biosynthetic reactions and other processes involved in assimilation and growth. Respiration rate increases linearly with temperature up to about 35 C and ceases at about 50 C in most temperate plants. The energy of photosynthesis in excess of that used in respiration is available for plant growth (net primary production, NPP).

The rate of photosynthesis and the efficiency of energy and water use in NPP appears to be greater in those plant taxa where the initial products are four carbon compounds. These include grasses which are members of the subfamily Panicoideae (except for one subgenera of Panicum) and Eragrostoideae. Other genetically controlled factors also influence net primary production so that efficiency varies with ecotype and species.

Photosynthetic and respiration rates decline with advancing maturity of leaves especially as they approach senescence. Since respiration occurs in all plant organs, but photosynthesis occurs primarily in leaves and to a lesser extent in sheaths and stems, and since rate of photosynthesis is much greater in young than in mature or senescing leaves, NPP is greatest when the vegetation has the highest percentage of young, rapidly-photosynthesizing leaves. Thus, net primary production is determined by the site constants, the driving variables and human use.

A portion of the NPP is consumed by herbivores, some of which are consumed by carnivores (and parasites), some of which in turn are consumed by other carnivores (and parasites). Herbivory, carnivory and parasitism are rarely, if ever, complete. Some organisms escape consumption, die and enter the detrital food web. For each animal in each web energy losses occur in the excreta (feces or feces plus urine), gases, and the work of digestion. The energy left (net energy) is available for growth, reproduction, work, and secretions (mild, hair, wool, etc.). Energy losses between trophic levels are very large and the number of trophic levels rarely exceeds five. Overconsumption by any trophic level reduces food supply and induces stress. Trophic level interaction is an important mechanism for maintaining ecosystem stability.

Processes of herbivory include grazing or chewing, sucking, and seed and nectar consumption. Herbivory may accelerate or retard NPP. For example, grazing may accelerate NPP by increasing the proportion of young leaves and, conversely, may retard NPP by excessive removal of photosynthetic tissue, especially when young leaves are selectively removed. NPP removal by sucking herbivores may accelerate photosynthesis, but if an excess is removed, may retard NPP because of a shortage of energy, amino acids, or water.

Herbivory affects the plant community in various ways. Herbivory is almost always selective. Thus, grazing animals select the particular parts of preferred plant species growing in convenient areas first.

As grazing pressure is increased, less preferred parts of less preferred plants are selected in less convenient areas. Those plant taxa that escape grazing or that are more grazing resistant are better able to compete and thus increase, changing the structure of the plant community. Also, herbivory involves things other than herbage removal. Trampling, manuring, wallowing, burrowing, etc. are auxillary activities which may have important effects on ecosystem structure, on NPP, the hydrological cycle, and other cycles of matter.

Cycles of Matter

These cycles involve the living and non-living factors of the environment (biogeochemical cycles) and usually link the processes of more than one ecosystem. These cycles involve a large slow-moving abiotic reservoir and a rapidly cycling pool that exchanges between organisms. Cycles of water and nitrogen are examples of those involving a gaseous reservoir. Cycles of phosphorus and calcium are examples of those involving reservoirs in the earth's crust. Microorganisms play very important roles in the cycle of nitrogen and sulfur. Human use often short-circuits these cycles which in turn disrupts energy flow and affects ecosystem structure.

SUMMARY

Ecosystem structure and function are subject to dynamic change within limits imposed by the site constants, driving variables, and the self-regulating mechanisms of the ecosystem. Various kinds of terrestrial ecosystems differ in the magnitude of different parameters of structure, function, dynamic change, self-regulatory mechanisms, potential human uses, responses to various human uses, and the characteristics of wise management. However, the basic principles of ecosystem operation appear to be the same and thus provide a framework for education, research and application in natural resource management.

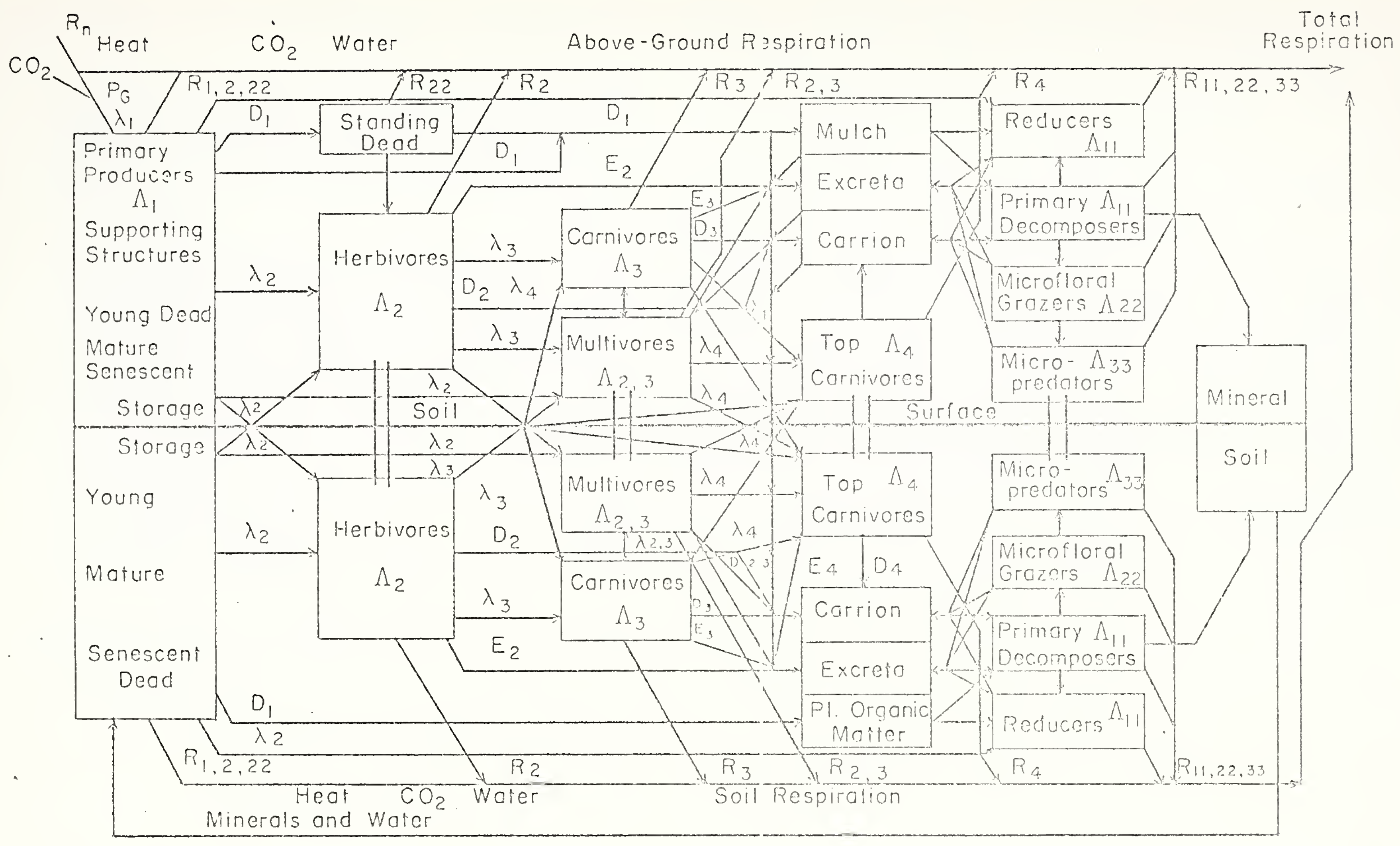

Fig. 1. Schematized compartment diagram with pathways of energy flow indicated by arrows for a semiarid, temperate grassland ecosystem (from Lewis, 1970).

Data are graphed on log scale from left to right for the ungrazed treatment and from right to left for the grazed treatment using data from Tables 4 and 8. Actual values are shown in the bars. Major compartments are graphed from the margins. Subcompartments are indented. Numerals following the major compartment designations are precision of estimate codes (Table 8). Abbreviations are as follows:

DET: Detrital food web
RED: Reducers
MFG: Microfloral grazers
MPR: Micropredators
BSC: Belowground standing crop of primary producers
MUL: Mulch
OLD: Standing crop of old dead primary producers
ASC: Aboveground standing crop of live plus current year's dead primary producers
CGR: Cool season grasses
WGR: Warm season grasses
CFO: Cool season forbs
WFO: Warm season forbs
SHR: Shrubs and semishrubs
SUC: Succulents
HER: Herbivores
ROD: Rodents
CHI: Chewing invertebrates
SUI: Sucking invertebrates
BIR: Birds
CATT: Cattle (hypothetical standing crops)
CAR: Carnivores

Multivore biomass was allotted to herbivores or carnivores on the basis of estimation of food habits.

NA: Not available
NC: Not calculated
ND: Not determined

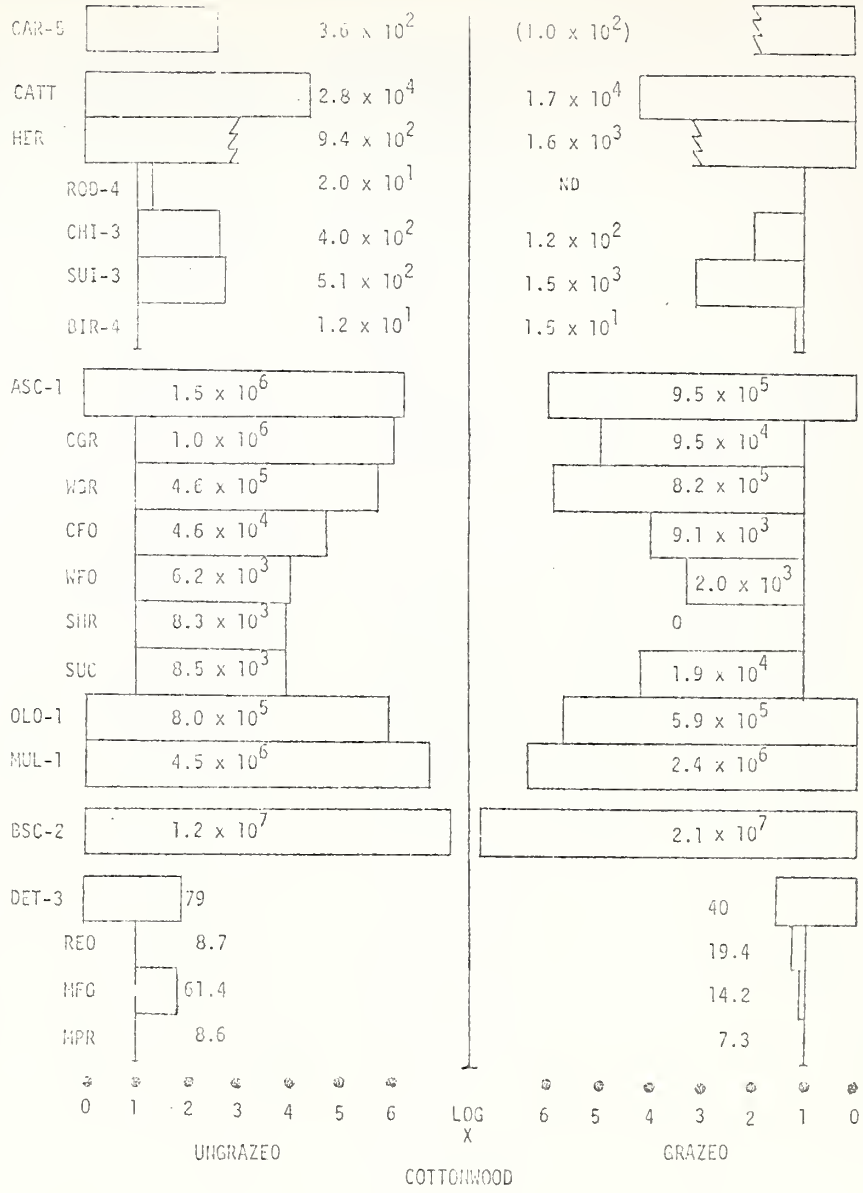

Fig. 2. Standing crops (time-weighted means for the potential growing season, g/ha ovendry) of various primary producer and consumer compartments in a mixed prairie ecosystem, relatively undisturbed (ungrazed) and recently disturbed (grazed) by cattle grazing, Grassland Biome, Cottonwood, 1970.

MODELS FOR ECOSYSTEM MANAGEMENT

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Introduction to Course Concepts

There can be little doubt that management of public lands is to be for the benefit of the public. Both the legislation which directs the management and the tradition of the land management agencies point to this end. Thus one possible starting point for a course in ecosystem management would be the identification of public needs which the management of public lands can help meet.

Most public land managers have been found in various aspects of ecology, and operationally many land management practices are developed from an ecological base. A full understanding of the ecology of any land area is probably beyond the budgetary limitation of most land management agencies. Thus identification of key ecological points should provide considerable help, and this approach could also provide a starting point for our discussions.

As teachers, however, we learn that we should start with those concepts and issues which are most familiar and of greatest concern to the students. Land managers spend their professional lives making land management decisions, and a starting point of decision making processes is another alternative starting point.

It is this latter view that we will adopt in this short course. The first phase will have decision making frameworks which have been found useful to land managers. Hopefully this will create a base for identifying key ecological information which will be covered in the second phase. Methods of handling ecological information will be treated in the third phase, and relationships of social needs will be covered in the fourth phase (Fig. 1).

Because a firm concept of ecosystem management decision model is so central to the managers' overall concepts, we will spend considerable time formalizing this area and gaining practical experience. The objective will be to so firmly entrench the basic concepts and operational skills into each student that these sessions will provide a firm framework for the succeeding phases. Each of the following discussions are intended to fill in some aspect of the overall concept.

Decision Models

During the short course we will present methods of treating such problems and reinforce the presentation with many opportunities for hands-on practice. A clear, firm grasp of the procedures is necessary.

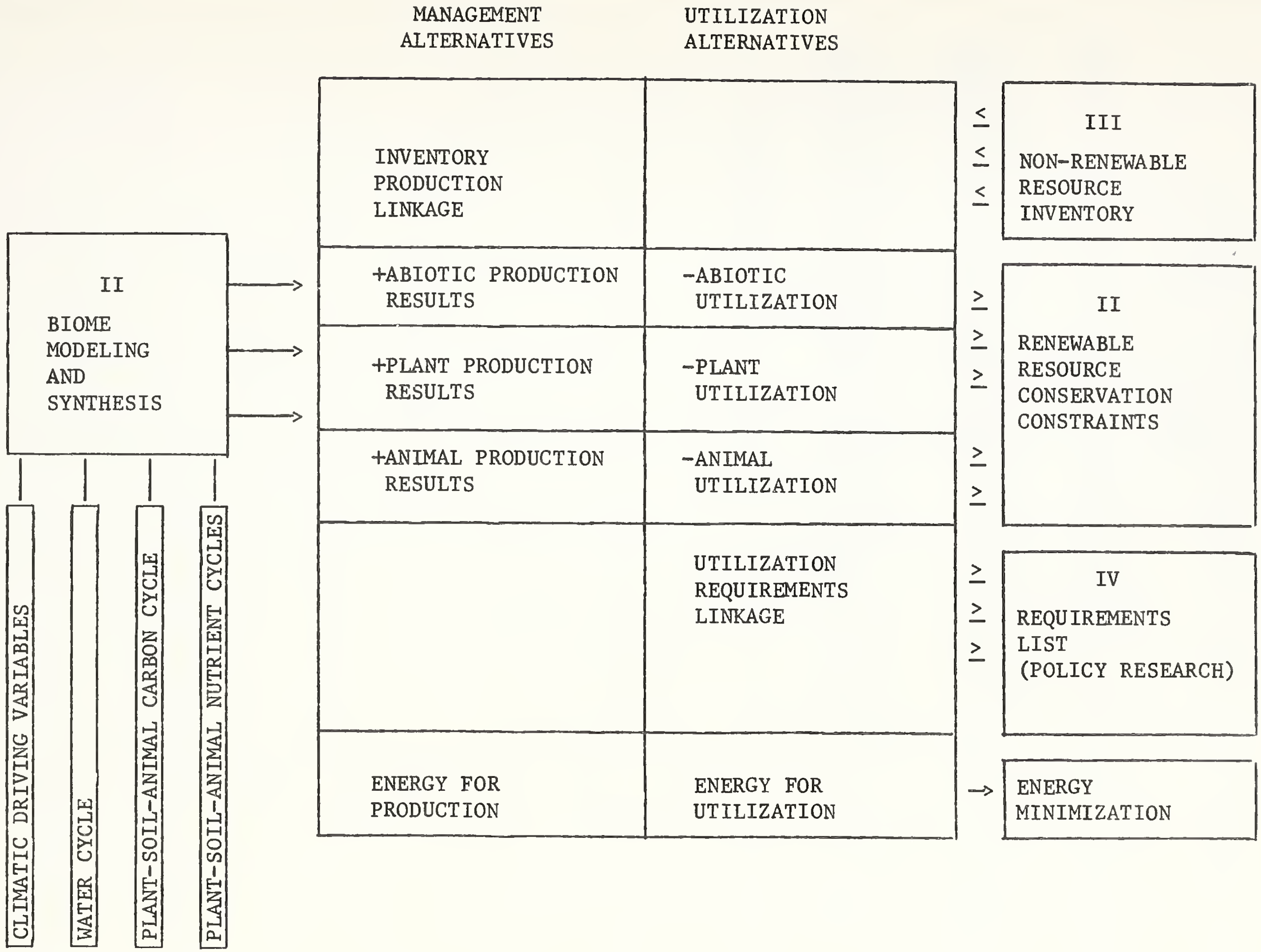

Fig. 1. Relationsnip of ecological models, natural resource management, and policy activities.

A decision model for a resource system includes:

(i) a resource inventory,

(ii) a list of management goals or requirements,

(iii) a mechanism or plan for converting the resources available to the achievement of the goals, and

(iv) an efficiency criterion.

Attributes (i) and (ii) are both included in the "right-hand-side" of the problem. Items in (i) will be listed as less-than-or-equal-to constraints ($\leq$), and items of (ii) will be shown as greater-than-or-equal-to ($\geq$).

Attribute (iv) is technically called the "objective function" of the problem, but the real objectives may be shown in (ii). The solution procedure is to minimize the cost of the objective function (or maximize revenue, which is the same thing).

Attribute (iii) is called the matrix of the problem. In the matrix we list the management alternatives to be considered, the use of resources of each category (i), by each alternative, and the contribution of each alternative to the requirements of (iii).

The solution of the problem is the number of units of each alternative to be implemented.

PRODUCTION THEORY AND RESOURCE OPTIMIZATION

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October, 1972

In any economy, with a given "bundle" of resources, the problem of resource management is to allocate resources in such a manner as to either arrive at a level of outputs (products) that will maximize net revenues or to determine the least-cost combination of factor inputs (resources) that will supply a specialized level of output. In either case, various private and public enterprises within the economy will compete for the scarce resources. These "bundles" of scarce resources may be composed of "stock" resources (land areas), "flow resources" (forage and/or timber production) and other necessary resources such as "labor" and supplemental resources (supplemental feeds such as wheat and corn).

The purpose of this seminar is to examine initially, the Production Economic Theory that is necessary to help determine the position of optimum resource allocation; i.e., that position where the physical (biological) optimum is equal to the economic (market) optimum. Second, once the Production Theory is discussed, we will examine the major considerations for determining optimum use of resource systems. Finally, in order to achieve optimum allocation of resource systems, a management model is developed. Our consideration in the development of a model will be in a framework that will allow managers to develop optimum plans for their particular situations.

SECTION I: PRODUCTION ECONOMIC THEORY

There are three major relationships in production economic theory:

(A) Factor-Product Relationship - the use of a single variable input (water) in conjunction with a fixed resource input (land).

(B) Factor-Factor Relationship - the consideration of differing physical quantity of more than one resource input for the production of a set quantity of output.

(C) Product-Product Relationship - the use of fixed quantity of resources in the production consideration of two or more products so as to maximize net revenue returns.

Traditional production economic theory identifies profit maximization as the overriding objective of competitive producers. When several variable resources are used by the competitive firm, two problems are solved simultaneously by the firm in the process of maximizing its profits (net revenues). It must use resources in the correct (least-cost) combination and it must use the absolute amounts (of the resources) necessary to produce that quantity of products which maximize profits. In analyzing the three (3) basic relationships of production economics,

we wish to clarify the positions for optimum resource allocation.

FACTOR-PRODUCT RELATIONSHIP

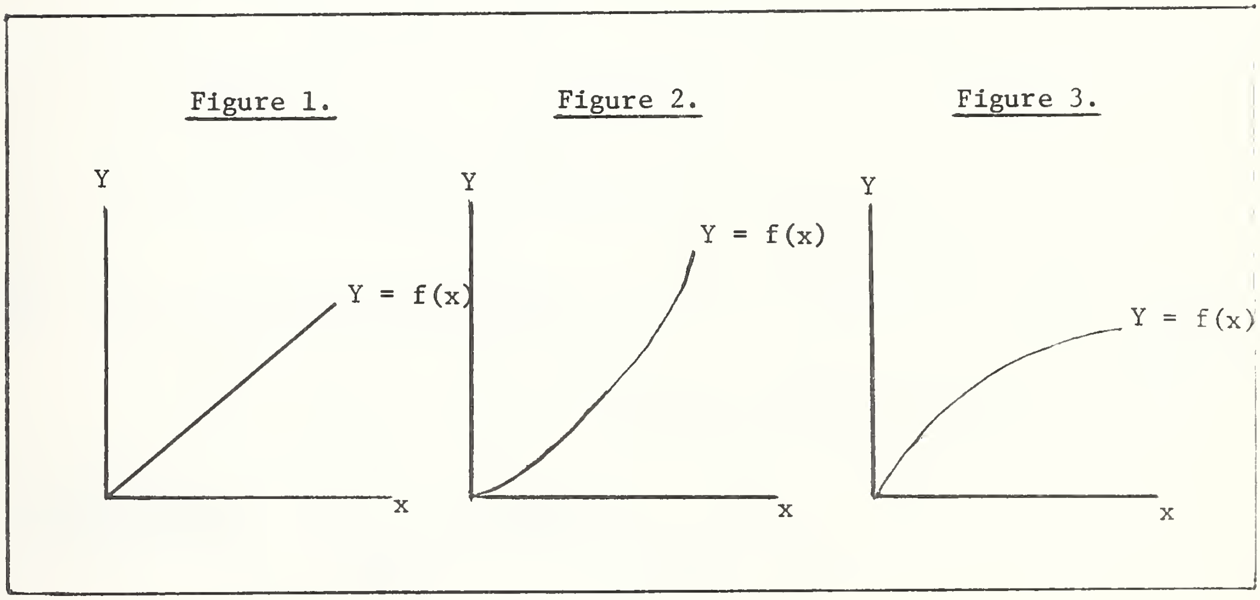
How much production (quantity) of a given commodity can be produced with a given quantity of factor input - natural resources, human labor, etc.

Y = output (board feet of timber)
x = factor input (labor)

therefore: Y = f(x) - single variable input case
- the assumption here is to consider the addition of a variable input (labor) to a fixed input (land -a timber stand in any given time period is fixed) and examine the change in physical production levels.

There are three (3) possible factor-product production relationships:

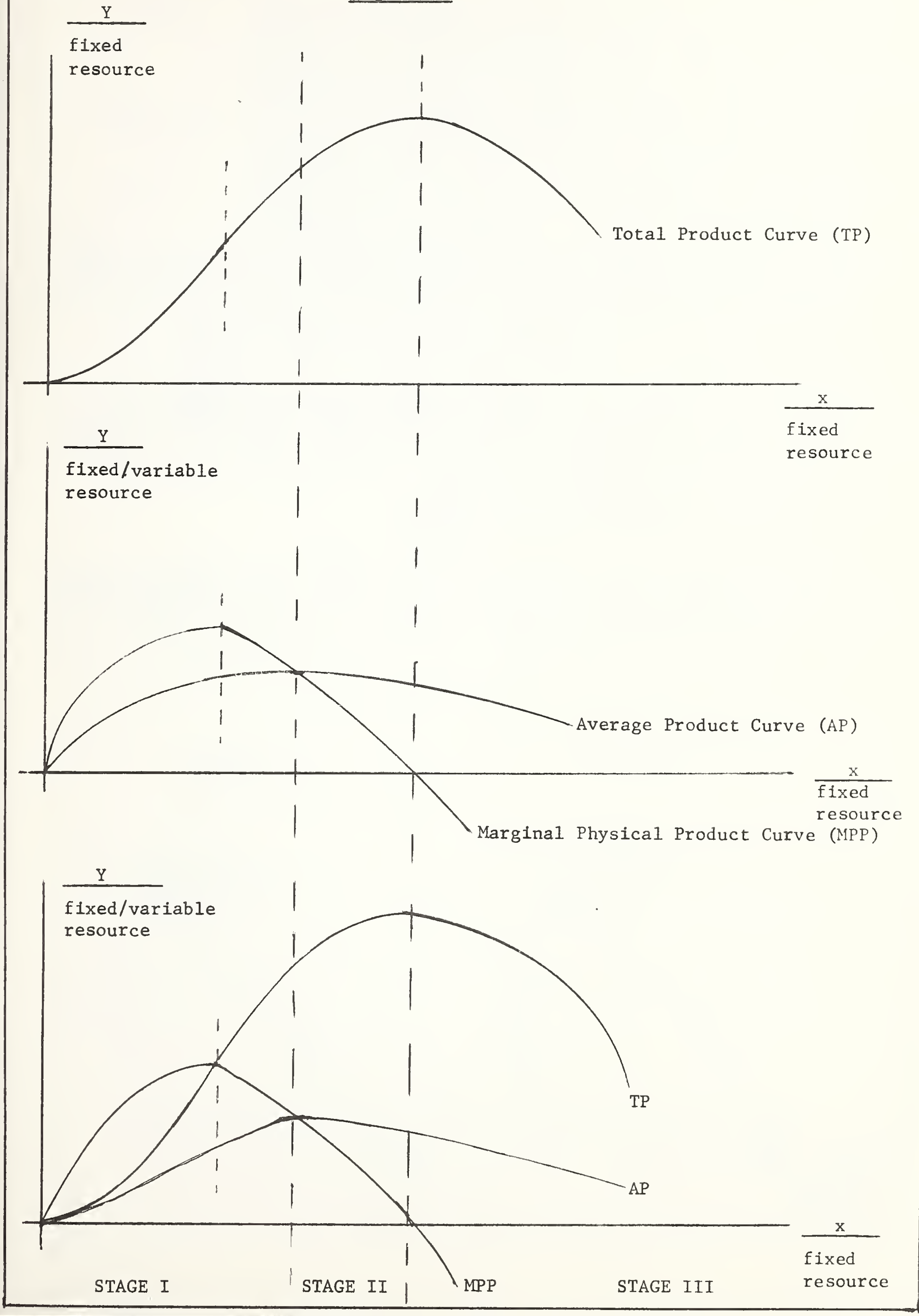
(1) Constant Returns (Figure 1) - if the factor input is increased by a set amount, the resulting output increases by a constant amount.
(2) Increasing Returns (Figure 2) - if the factor input is increased by a set amount, the resulting output increases by increasing amounts.
(3) Decreasing Returns (Figure 3) - if the factor input is increased by a constant amount, the resulting output is increasing by a decreasing amount.



The decreasing returns case (Figure 3) is the most typical case in resource allocation; i.e. law of diminishing returns which states as a variable resource (labor) is added to a fixed resource (land), each additional unit of labor will contribute less to the quantity of Total Product (board feet of timber).

Figure 4 outlines a series of diagrams which help to denote the shape of the "real world" production functions. The production function has three (3) stages of production:

Figure 4.


Y
fixed resource
Total Product Curve (TP)
x
fixed resource
Y
fixed/variable resource
Average Product Curve (AP)
x
fixed resource
Marginal Physical Product Curve (MPP)
Y
fixed/variable resource
TP
AP
x
fixed resource
MPP
STAGE I
STAGE II
STAGE III

Stage I: - First part the marginal physical product (MPP) is increasing; therefore, foolish to stop production.
- Second part - marginal physical product (MPP) is decreasing however, average product (AP) is still rising; therefore still profitable to continue production.

Stage III: - Very irrational stage of production Total Product (TP) is decreasing - each additional unit of input (x) decreases quantity of Total Product - must stop production.

Stage II: - Rational stage of production MPP is positive - TP is still rising; but AP is falling - somewhere in Stage II is the optimum level of production.

Thus, we know that the physical optimum exists somewhere within Stage II of the production process. We can conclude here: in order to maximize profits, given resources (labor and land) must be combined in a manner such that:

(a) greater output may not be forthcoming through the use of same amounts of the variable input (labor); or,

(b) the same amount of output (timber) may not be produced with fewer inputs.

The optimum production position depends on optimum use of the variable resource - must look at price of factor input and product output. The sufficient condition for economic efficiency in the factor-product situation is:

Price of the factor input = Value of the Marginal Product of the input used for the production of a specific product (timber).

$$P_x = VMP_x$$

Figure 5 denotes the relevant portion of the MPP curve from Stage II at the production process. All values of this part of the curve are multiplied by the market price (P_Y) of the product (timber) and then we obtain the value of marginal product curve. (VMP = Figure 6)

Figure 5.

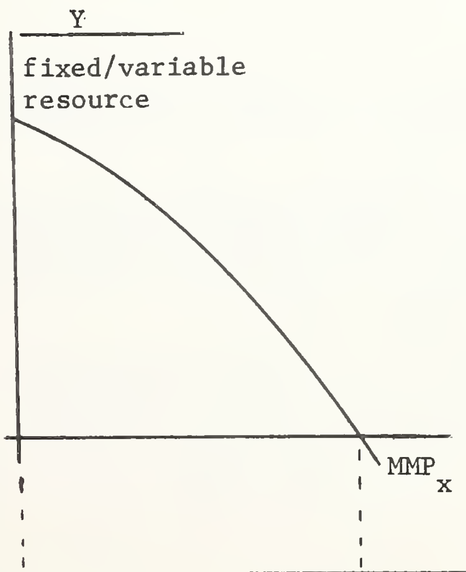
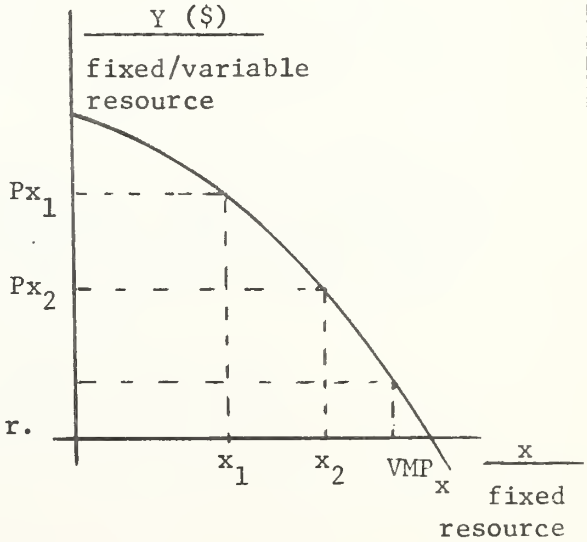


Figure 6.



Since Stage II is the only relevant area of efficient physical production; we only consider that part of the MPP curve that is in Stage II.

$$MPP_x \cdot P_Y = VMP_x$$

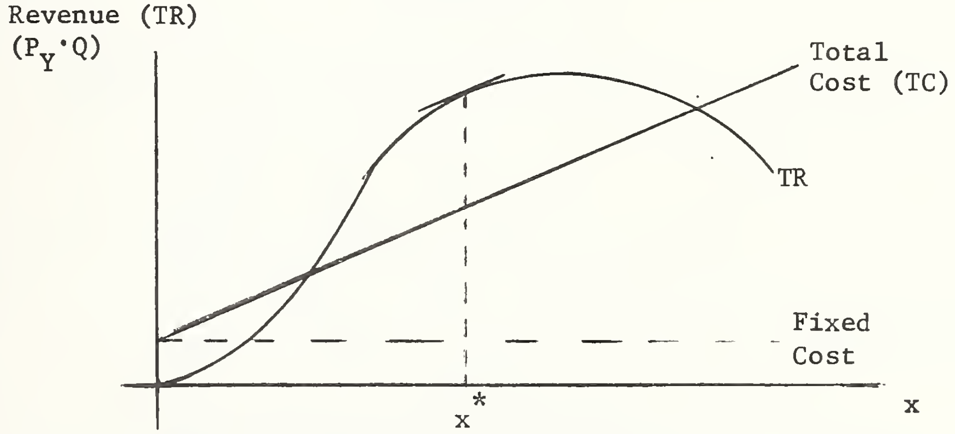
VMP now considers the production in dollar (economic) terms. Thus we arrive at both a <u>physical</u> and <u>economic</u> optimum when:

$$P_x = (\Delta Y/\Delta x) \cdot P_Y$$
$$P_x = MPP_x \cdot P_Y$$
$$P_x = VMP_x$$

Finally, if the P_x changes, then the optimum quantity of x (factor input) employed will also change (Figure 6). In the second part of this seminar we will further examine implications of the value of the marginal product concept.

By looking at the <u>net</u> difference between total costs and total revenues we can obtain the position of maximum net revenues (benefits). Figure 7 denotes both a Total Cost (TC) curve and a Total Revenue (TR) curve. Whereas the TR curve is not at straight line (same reasoning

Figure 7.



as TP curve), the TC curve is a straight line (cost of variable resource (x) is constant at any given time period).

In economic terms, the optimum production is when the marginal cost of producing an additional unit of output is just equal to the marginal revenue obtained from the sale of that product. This occurs in Figure 7 when the slope of the TC curve is equal to the slope of the TR curve.

$$TR - TC = \text{Maximum net revenue}$$

$$\text{Slope of TR curve} = \text{1st derivative of TR} = MR$$

$$\text{Slope of TC curve} = \text{1st derivative of TC} = MC$$

$$\therefore MR = MC$$

$$P_x/P_Y = \Delta Y/\Delta x$$

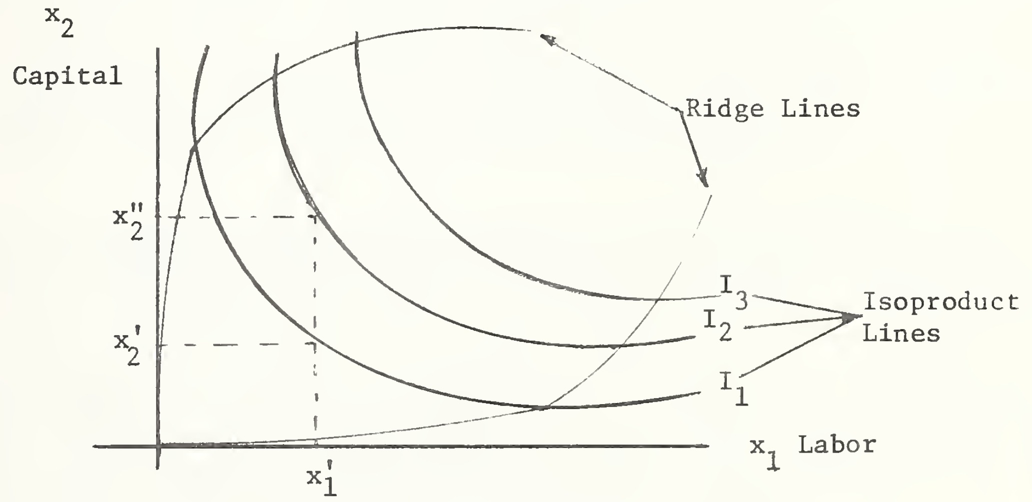
$$\Delta TR = \Delta TC$$

$$MR = MC$$

FACTOR-FACTOR RELATIONSHIP

Having established the conditions for optimum use of a specific variable resource, we now consider the use of two or more variable resources (factors) in the production of a specified level of product (output). What must be developed is a scheme to consider all possible combinations of, say two factors - labor (x_1) and capital (x_2) which may produce the same predetermined quantity of product; i.e. timber. Figure 8 shows a "isoproduct" curve which is the most typical case. The curve denotes a physical "marginal rate of technical substitution" (MRTS). The MRTS gives the slope of the isoproduct curve. Figure 8 shows the

Figure 8.



differing quantities of x_1 and x_2 that may be substituted for one another to allow for the production of 100 units of timber. In the relevant range of product (Stage II - the area between the "ridge lines"), as we increase the use of x_1; the quantity of x_2 used must decrease and vice versa.

In Figure 8, we denote three (3) different isoproduct curves (I_1, I_2, I_3). Each of the isoproduct curves indicate a different level of production; i.e. I_1 = 100 units, I_2 = 200 units and I_3 = 300 units. If we decide on using x_1' of labor to produce 100 units of timber, then we must simultaneously use

x_2' of capital. If, however, we wish to produce 200 units of timber and only continue to use x_1' of labor we must almost double our use of x_2 to x_2''.

FACTOR-FACTOR CASE: LEAST-COST COMBINATION

To this point we have examined the physical combinations of two or more factors of production. In order to determine the least-cost position with respect to using factors in a production process, we must consider the economic (market) involved in resource use. For the least-cost combination of two factors (x_1, x_2) in the production of a specified level of output (denoted by the isoproduct line), we must satisfy both the optimum physical and economic conditions. We must satisfy those physical conditions where the marginal rate of technical substitution ($MRTS_{x_1 \text{ for } x_2} = \Delta x_2/\Delta x_1$) be equal to the market rate of substitution denoted by the price ratio (Px_1/Px_2):

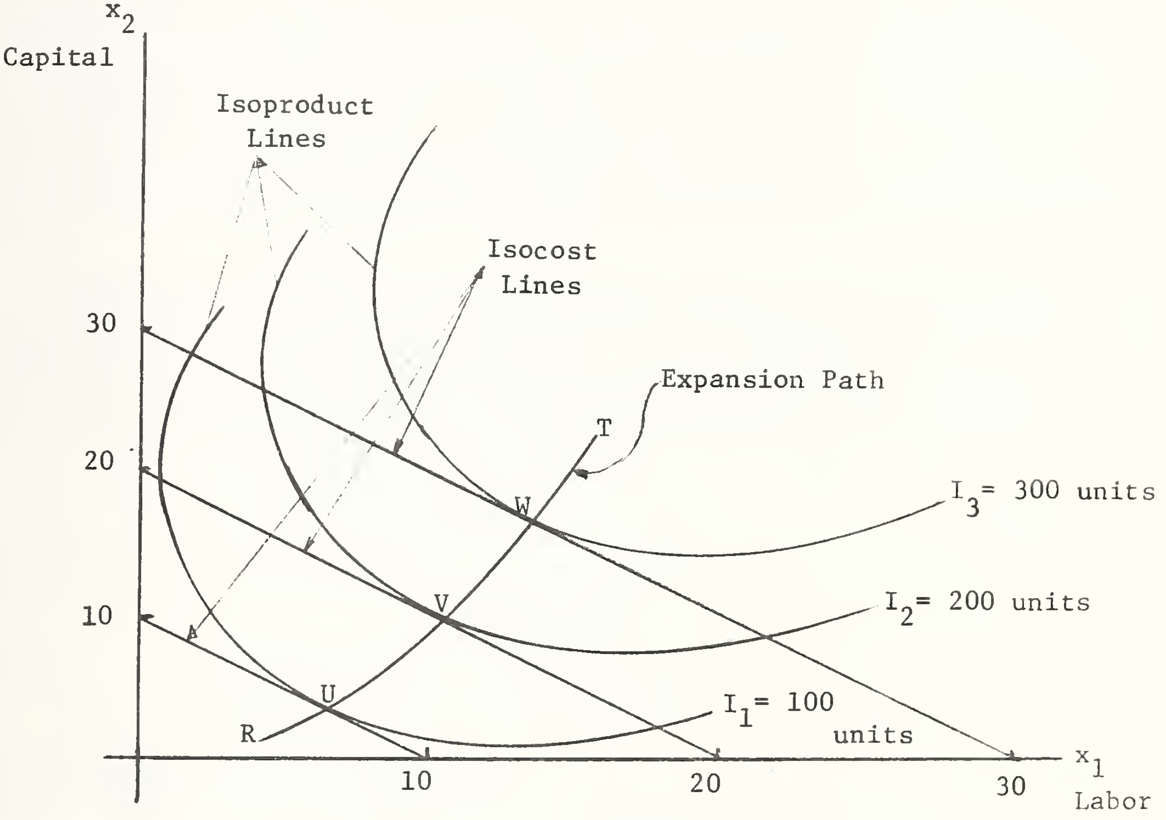
$$MRTS_{x_1 \text{ for } x_2} = \Delta x_2/\Delta x_1 = Px_1/Px_2$$

The physical constraints ($\Delta x_2/\Delta x_1$) are denoted by the slope of the isoproduct line. In order to establish the economic constraints, we must construct an isocost line. The isocost line shows all possible combinations of factors (x_1 - labor, x_2 - capital) which require the same cost outlay (budget constraint). Since the factor prices are determined by the market system, there exists a linear relationship between the prices. The slope of the isocost line is denoted by the price ratio (Px_1/Px_2).

Figure 8 outlined three possible levels of timber production. In Figure 9 we construct isocost lines based on expected factor prices and then determine the "tangency" position for the isocost lines and the isoproduct lines. At the point of tangency, the slope of the isoproduct line ($\Delta x_2/\Delta x_1$) is equal to the slope of the isocost line (Px_1/Px_2). This then is the optimum level of resource use for each level of production. The level of production that is finally selected will be constrained by budget limitations. The larger the budget, the larger the quantities of factors (labor, capital) that may be purchased and, thus, the larger the quantity of product.

If however one is not limited by a budget, we may wish to determine which level of production (100, 200, or 300 units of timber) is in fact the optimum level of production. The line RT in Figure 9 denotes an expansion path - any point on the expansion path is a tangency point between an isoproduct line and an isocost line and thus a least-cost production point. Each least-cost production point will have a total cost (TC) and a total revenue (TR) associated with that specific production level. The TC is based on quantities of resources (x_1, x_2) used and the TR is based on the price of the product (P_{timber}) multiplied by the quantity of timber. As explained in an earlier part of this seminar, the optimum least-cost production level will be where the marginal revenue (MR) is

<u>Figure 9.</u>



Assume: Price of Capital (Px_2) = \$2.00
Price of Labor (Px_1) = \$1.00

Slope of isocost line = Px_1/Px_2 = 1.00/2.00 = 1/2

Isocost line = budget line

If budget = \$20 may purchase either 20 units of labor or 10 units of capital or some combination between these extremes - if budget = \$60 may purchase either 60 units of labor or 30 units of capital or some combination between these extremes.

equal to the marginal cost (MC).

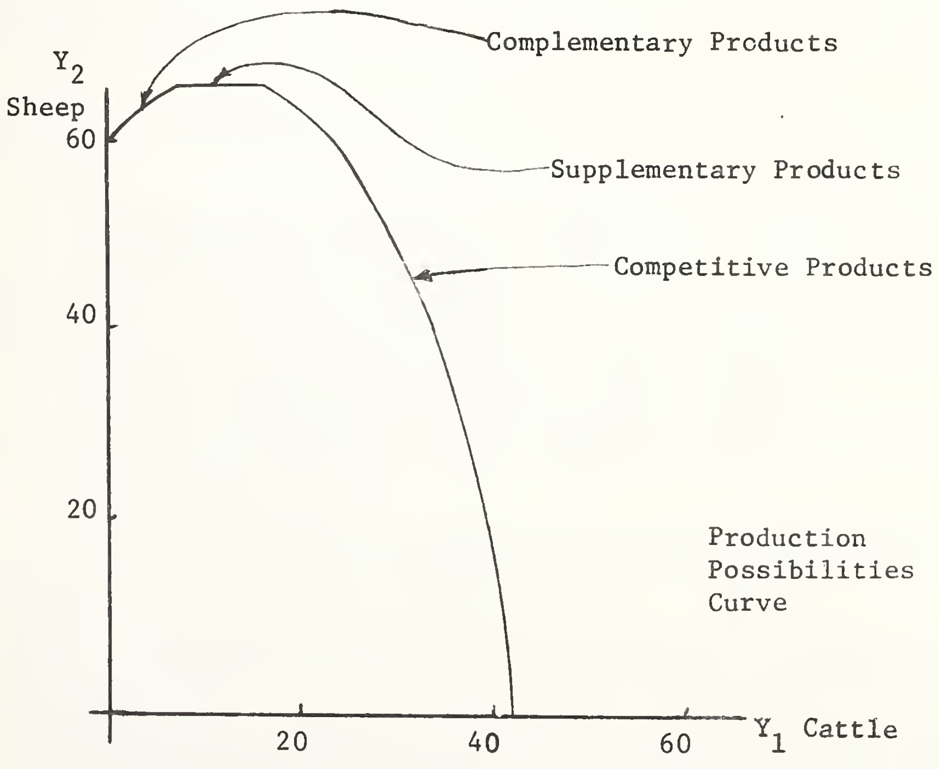
PRODUCT-PRODUCT RELATIONSHIP

Of prime importance to managers of resource systems is the problem of how best to use a "bundle" of available resources in a production system. Given a fixed amount of available resources (x_1, x_2, x_3.....x_n) associated with a given land area (X), how may we select an optimum combination of two or more products so as to maximize total net returns. We are not necessarily interested in maximizing physical returns but, we are concerned with maximizing net <u>value</u>. In the public sector we may be concerned with maximizing net "social welfare", whereas in the private sector our main concern may be to maximize net revenues. In some instances, both the public and private sector may be satisfied by the same production position.

Figure 10 outlines three (3) extreme types of production possibilities. <u>The Production Possibilities Curve</u> shows all possible combinations of two outputs (Y_2 = Sheep, Y_1 = cattle) which can be produced with a fixed quantity of inputs. This curve denotes the <u>physical</u> marginal rate of product substitution (MRPS) and is also called the "isoresource" curve.

$$MRPS_{Y_1 \text{ for } Y_2} = \Delta Y_2 / \Delta Y_1$$

Figure 10.



The complementary range of the production possibilities curve indicates that an increase in the output of one product (Y_1 = cattle) is accompanied by an eventual increase in the quantity output of the other product (Y_2 = sheep). In our specific grazing example, the above may result if by increasing the quantity of one product (Y_1 = cattle), this product contributes to better management of the land resource, thus increasing the resources available for use by the second product. If a complementary situation exists, there does not exist the problem of conflicting resource use. To observe such a relationship, one must consider several production periods.

The supplementary range of the production curve is reached when the output of one product may be increased (Y_1 = cattle) with no resulting decrease or increase in the output of the other product (Y_2 = sheep). This may occur if we have cattle and sheep on the same range area, where the animal types each consume different types of variable resources (cattle prefer grasses whereas sheep prefer forbs or browse). In this type of situation we again assume that there exists no competition for the resources.

The most common production relationship is when there exists product competition for the bundle of resources. In this case, as we increase the quantity of Y_1(cattle) in successive substitutions, the production of Y_1 (sheep) decreases but by increasing amounts. The decrease in the production of Y_1 by increasing amounts is a result of the complete loss of the complementary and supplementary effects of resource use in a competitive situation.

From the preceding discussion we can summarize and determine the rational area of production:

(1) As long as we can increase the output of one product without simultaneously reducing the production of the second product, we will continue to produce increased quantities of that product at least to the point where the products become competitive.
(2) If we can increase production of both products at the same time, we will again produce at least enough of both products so that competition for factor supply occurs.
(3) The rational combination of production of two outputs thus, will lie somewhere in the competitive range of the production possibilities curve.

OPTIMAL POSITION-BOTH PHYSICAL (BIOLOGICAL) AND ECONOMIC

Like the factor-factor and factor-product relationships, we must now examine the product prices (P_{Y_1}, P_{Y_2}) in order to determine the optimum product mix. Figure 11 denotes the assumed production function for both sheep and cattle. In terms of a physical units, a unit of resource (x) will produce a greater unit of sheep than cattle. Given these

Figure 11.

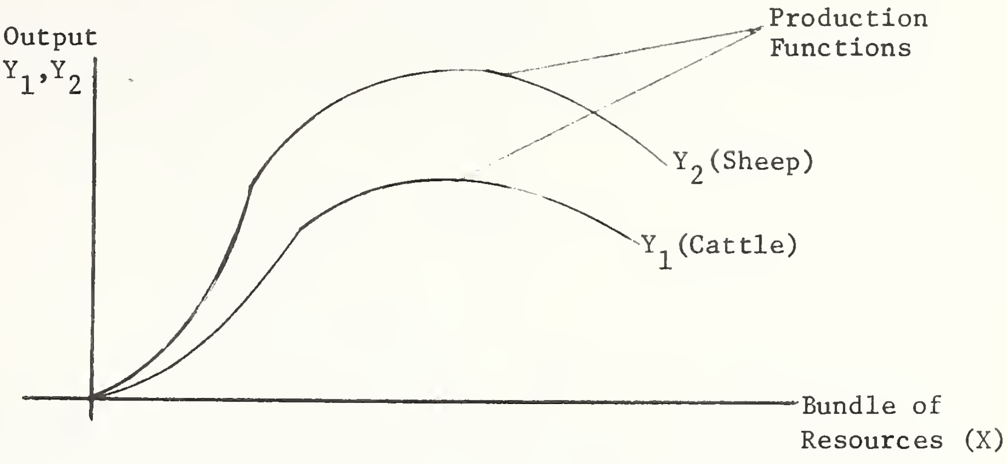
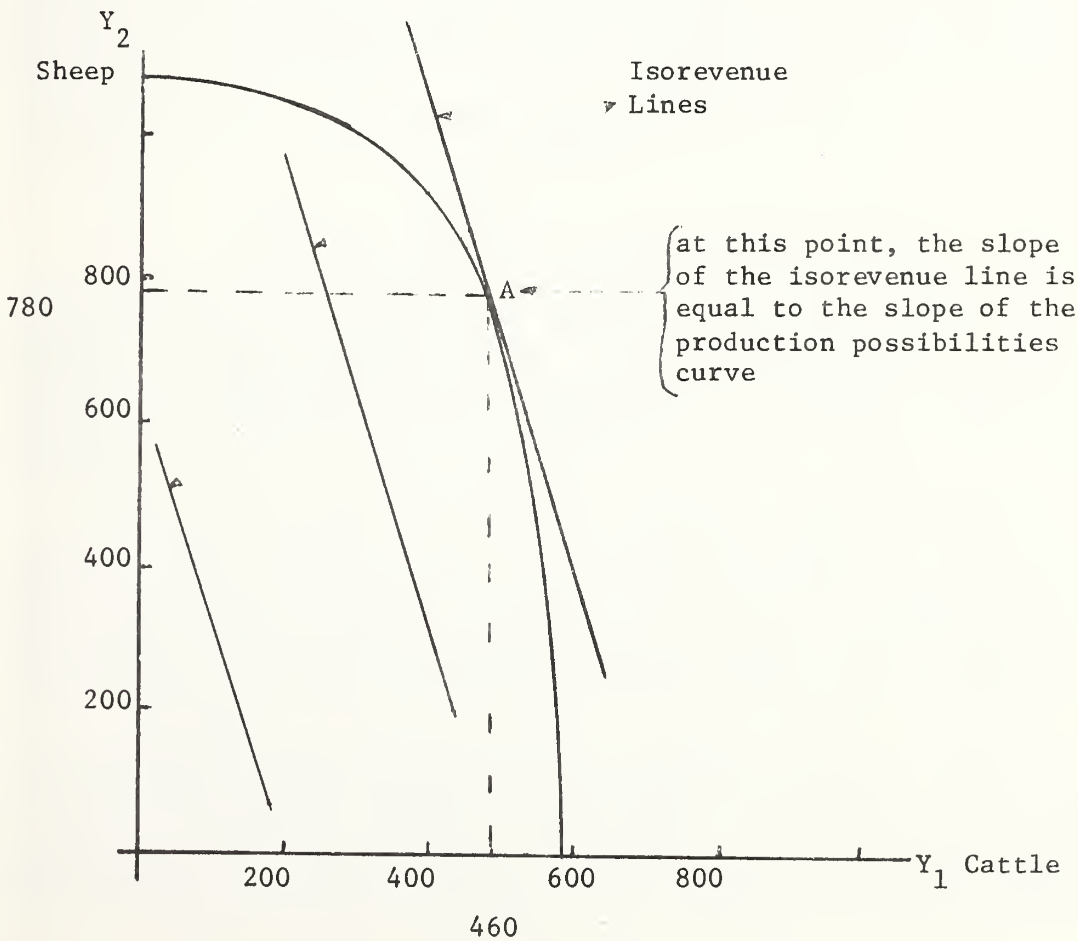


Figure 12.



production functions, we can now derive a production possibilities curve for sheep and cattle (Figure 12). In order to arrive at an optimum combination of product output, we must arrive at a position where there exists equality between the physical possibilities and the economics market conditions (denoted by the price ratio (PY_2/PY_1). If we assume the market prices to be:

$$PY_2 = \text{sheep} = \$\ 90.00$$

$$PY_1 = \text{cattle} = \$270.00$$

then, the price ratio is equal to:

$$PY_2/PY_1 = 90/270 = 1/3$$

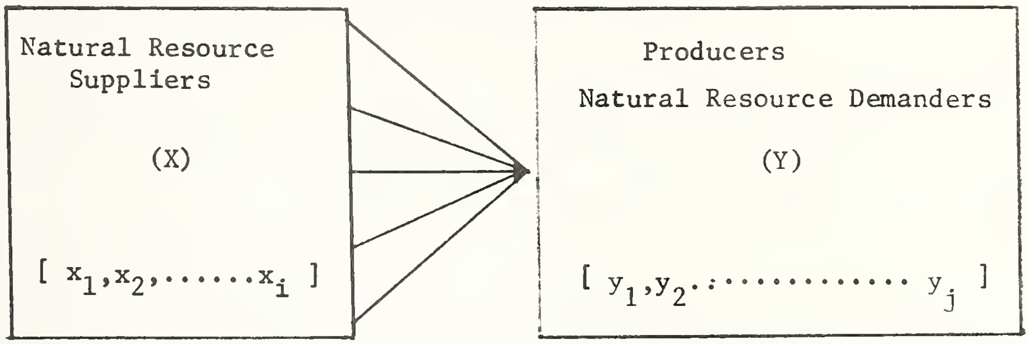
Thus we have a line with a slope of 1/3. This line is known as an <u>isorevenue line</u>. The isorevenue line denotes a set level of gross revenues that will result from the production of various quantities of both sheep and cattle. In Figure 12, we show 3 different isorevenue lines. Each isorevenue line denotes a different gross revenue value. The further we move away from the origin the larger the gross revenue. The optimum level of production will occur when a specific isorevenue line is just tangent to the production possibilities curve (Point A in Figure 12). At the point of tangency, the slope of the isorevenue line (PY_2/PY_1) is "just" equal to the slope of the production possibilities curve. Thus, we have arrived at the optimum production level (in our example, 780 sheep and 460 cattle) which maximizes net revenues and where, the value of the marginal product of the last unit of x used to produce sheep ($VMP_{x_i} \text{ for } Y_2$) is equal to the value of the marginal product of the last unit of x used to produce cattle ($VMP_{x_i} \text{ for } Y_1$).

SECTION II: OPTIMUM USE OF RESOURCE SYSTEMS

The basic production relationships we discussed to this point have dealt with either allocating resources to produce a specified level of output at the least possible cost or allocating resources in such a manner as to maximize net returns from production. The graphic examples we have used are two-dimensional thus, consideration of optimum allocation of resources is limited to two resources (two factor inputs) and two products.

In the real world, the problem of resource supply and demand is much more complex. Figure 13 denotes the more complex relationship between resource users (demanders) and the available "bundle" of resources (supplier). The question that arises is how best to allocate the bundle of resources (X) so as to maximize the net benefits to society. We assume that there exists no externalities arising from the decisions made. Each producer (y_j) will demand part of the bundle of resources (x_i) according to the needs of his production function. In the case of "scarce" resources, the quantity demanded is greater than quantity supplied. Thus, producers (users) will compete for the resources and, in a purely competitive situation, the price mechanism will be the allocation of the resources. The optimum situation is if each unit of resource is able to move freely

Figure 13.



to obtain its highest price. If this is the case, each "unit" of resource will contribute its highest possible value to society. We indicated this relationship earlier in our discussion of the factor-product relationship in production economics. This relationship

$$Px_i = VMPi_n$$
$$Px_i = MPPx_i \cdot Py_n$$

shows that the price paid for resource x_i must be equal to the values of its marginal product, i.e. that value the last unit of resource used contributes to the production of product (n). As denoted in Figure 13, the bundle of resources X may consist of a large number of variable resources (x_i). Also, the demanders of the resources (Y) for production use may be large in number (y_j).

It is apparent from the preceding discussion that there is a need for a programming procedure that will analyze supply and demand simultaneously in order to arrive at an optimum use of the resource system. The final section of this seminar will deal with such a model.

SECTION III: FRAMEWORK FOR RESOURCE OPTIMIZATION MODELS

In order to achieve optimum allocation of resources, a management model is developed. Equation 1 denotes the objective of the model which is allocation of the resources in such a manner as to maximize contribution margin (gross revenue returns net of variable costs; variable costs are those costs which vary with changes in the use of alternative management schemes):

$$Z_{max} = \sum_{k=1}^{T} \frac{\sum_{j=1}^{n} r_j y_j - \sum_{j=1}^{m} c_j x_j}{(1 + i)^k} \qquad (1)$$

Subject to a number of constraints and where:

T = length of total planning period under consideration;
n = number of final products under consideration;
r_j = value of each final product for j=1,.,n;
y_j = number of units of each final product for j=1,.,n;
m = number of possible management schemes in the problem;
c_j = cost per unit of each management scheme for j=1,..,m;
x_j = number of units of each specific management scheme for j=1,..,m;
k = time interval as part of total planning period; and,
i = the discount rate

The optimization model is best explained by discussing the various components of the model. Figure 14 denotes the partition notation for the linear programming model. Partition notation consists of a number of submatrices and subvectors which store data and are presented on the following pages of discussion.

1. Subvector (a) indicating the fixed resource inventory.

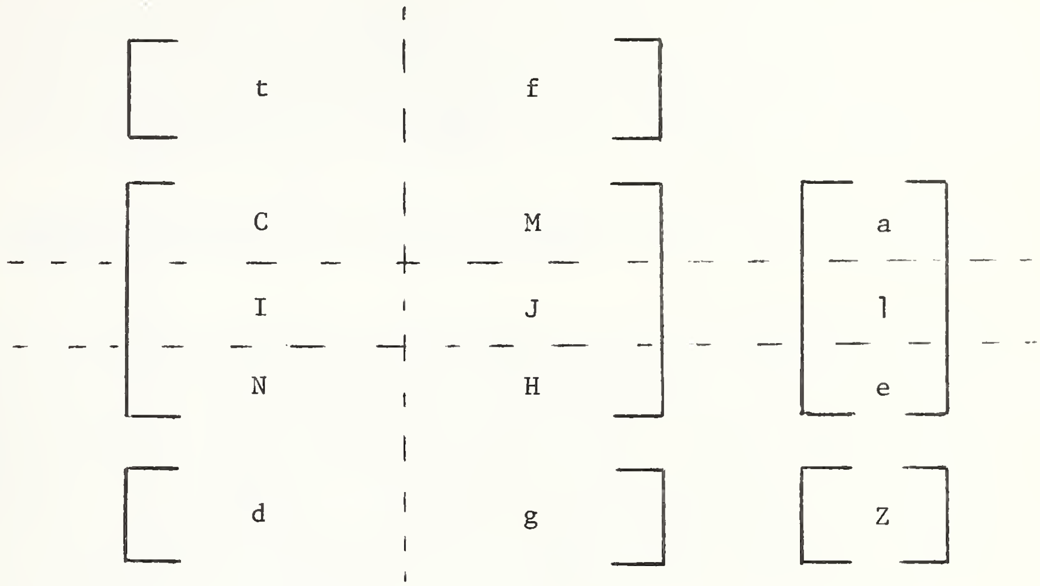
This includes classifications such as soils, topographic class, opportunities for water and timber development, etc. Such resources can be measured in appropriate units such as acres and number of opportunities. In the management of the resource system, various grades of a resource class, will, for most cases, be considered as separate resources. Thus a management unit will be based on the homogeneity of the area or resource "bundle." That is to say, each portion of a management unit will respond to a management alternative the same as every other portion of that unit. A high producing soil type will be considered a separate "stock" resource from a low producing soil type. Use of these classes lets us retain the simplistic view of a linear program formulation, but if we attempted to describe such classes by a continuous mathematical function we would very likely find ourselves working with a nonlinear problem. The subvector of fixed resource constraints is established by resource inventory techniques.

2. Subvector (t) listing a description of management schemes.

The operation of a resource system includes a set of management alternatives to be applied to all or part of the components of the vector of fixed resources. One possible management alternative that must be kept in mind is the "do-nothing" alternative. By "do-nothing" alternative, the resource manager will adjust his management plan according to the natural state of the fixed resources. Other alternatives might include such things as continuous versus rotation grazing, clear cutting versus selective timber cutting, brush control and reseeding, water development, fertilization, strip mining and crop harvesting versus crop grazing.

It is not uncommon in dealing with linear programming problems that a particular set of requirements exceeds the ability of the system to meet

Figure 14.



(a) Subvector of Fixed Resources

(C) Submatrix Linking Management Alternatives to Fixed Resources

(d) Subvector of Management Costs - Part of Objective Function

(e) Subvector of Quantity of User Requirements

(f) Subvector of Users(Products) - column vector, transposed

(g) Subvector of User Revenues - Part of Objective Function

(H) Submatrix Linking Users to Their Requirements

(I) Submatrix of Production Rates of Renewable Resources

(J) Submatrix of Utilization Rates of Renewable Resources

(l) Subvector of Lower Limit of Renewable Resources (generally zero)

(M) Null Submatrix to Complete the Array

(N) Null Submatrix to Complete the Array

(t) Subvector of Management Alternatives - column vector, transposed

(Z) Final Value of Objective Function

these requirements. When the problem is stated in this fashion, we arrive at what is known as an "infeasible solution".

Unfortunately, with most computer programs, an infeasible solution gives very few diagnostics as to the basic cause of the problem. A convenient way of avoiding these difficulties is to include in the management alternatives one which has a very high cost but is essentially without limit. In the ranching problem a good example would be the purchase of supplemental feeds which, when considered from the standpoint of an individual ranch operation, can be without limit. When, such a management alternative is included, a feasible solution is most often obtained.

3. Submatrix (C) linking management alternatives to fixed resource inventory.

Management alternatives, as discussed so far, utilize fixed resources and, of course, the amount of resource available cannot be exceeded. Thus, this submatrix is the linkage between the management alternatives and the resource limitations. Some management alternatives have zero or essentially zero linkage to the various resource constraints. For example, meadow fertilization, as a management scheme, is not adaptable for use on steep rocky slopes. On the other hand, other management schemes are completely coupled to the resource constraints; for example, the land area cultivated plus the land area not cultivated cannot exceed total land area.

If the management alternatives are expressed in the same units as the resource constraints, the matrix entries where coupling occurs will be ones, and all matrix entries where coupling does not occur will be zeros. Undoubtedly, there are examples where coupling is neither complete nor entirely lacking; in these cases the matrix entries would be something other than one or zero. If, for example, there exists a budget constraint for funds available for specific management schemes, the entries in the submatrix will represent the costs of these schemes.

Utilization of the resources by the various management alternatives may frequently be determined simply from a general background or knowledge of resource system functions provided that complete coupling or complete uncoupling are acceptable choices. Partial coupling generally requires some research evidence to give the appropriate value.

4. Subvector (d) listing the management costs.

For the purposes of our model, all management alternatives will be assumed to have costs only, and no benefits will be directly associated with the management alternatives. The benefits, denoted by increased production of various product classes, will be shown in another part of the model. Thus, we are not concerned with optimizing the returns from any single management alternative but are concerned only with the management of an entire resource system. The subvector of costs should be only those costs which can be assigned exclusively to the particular management alternatives in question. These costs are referred to as variable costs.

5. Subvector (f) designating description of users.

The elements in this subvector denote the various kinds of products to be considered in the optimization scheme. Products that may be considered are cow/calf units, various classes of steers (according to the different seasons), timber production and non-marketable products such as production of

various types of outdoor recreation and wild animal production. Any product (output) that will be considered in the study must be listed in subvector (f).

6. Subvector (g) listing the production gross revenues.

Some of the individual products that are listed in subvector (f) will produce gross revenue. A typical ranching operation, for instance, may associate gross revenues with steer production, breeding cow production, etc. Since variable costs associated with supplying factors of productions are entered as positive values in subvector (d), these gross revenues are entered into the total analysis as negative values (negative costs). Not all product classes, however, will produce gross revenues directly; for example, seed trees, antelope, etc.

7. Subvector (e) of user (product) requirements (quantity).

We have found it much more convenient to establish a vector of quantity requirements for various kinds of production and to investigate the resultant production variable costs and gross revenues with various sets of output requirements. By approaching the problem in this fashion we are spared the very difficult problem of assigning specific production costs to particular classes of production. In addition, some production classes are extremely difficult to assign a particular gross revenue. For example some minimum number of campgrounds may be required for picnicking, some specified number of seed trees may be required for adequate reforestation, etc. In order for these products to be competitive in the optimization model, they must show a competitive gross revenue return. This requires an ability to determine gross revenue values for non-marketable products; a very difficult task. Instead, by placing the quantity requirements in the subvector (e), the problem formulation is very greatly simplified. Although the requirements are set arbitrarily, the model can determine the opportunity cost of supplying the designated requirements.

8. Submatrix (H) linking users (products) to their requirements (quantity).

Submatrix H links the users denoted in subvector f to their quantity requirements (denoted in subvector e). This submatrix is only needed when specified quantities are to be considered for various users. Ordinarily this matrix will be either ones or zeros; the ones linking the users to their specified quantity requirements and the zeros indicating no linkage between users and requirements. If all products (users) are considered, the submatrix is an identity matrix.

9. Submatrix (I) showing production rates of renewable (flow) resources.

Contrary to the set of constraints which rigidly fix the amount of fixed resources available (subvector a), the renewable or "flow" resources are limited primarily by their production rates. Each of the various management alternatives (subvector t) can be thought of as modifying the production rate of the various renewable resources. Each management scheme under consideration will increase the production rate of flow resources by differing quantities. In the final analysis, the model will use that management scheme that contributes the greatest increase in the production rate of the renewable resources at the least possible cost.

It is characteristic of most renewable resources that, in order to

provide a continuing yield, only a portion of the renewable resources can be harvested in any planning period. Harvesting to a greater degree will reduce the capacity of the renewable resources to provide growth and thus would clearly not be acceptable in the long-term management view of an ecosystem. The amount that can be harvested from the total amount of land area, however, becomes a rather technical question in itself. For example, what is the allowable harvest of forage from a pasture area? For this lecture we will assume general rules of thumb developed from the experiment by management practitioners over the years which indicate the percentage of the standing crop of the renewable resource which should be utilized in any given year.

10. Submatrix (J) showing utilization rates of renewable resources.

This submatrix is paired with the set of production rates of renewable resources indicated in submatrix (I). Submatrix (J) denotes the various utilization rates of the flow resources by the users (product) under consideration in the optimization model. In submatrix (I) the entries in the cells are positive entries since they denote an increase in the quantity of renewable resources available as a result of the implementation of various management schemes. On the other hand, since the elements of submatrix (J) denote a decrease in the available quantity of renewable resources as a result of their being consumed by the users, the entries of submatrix (J) are negative values.

11. Subvector (l) indicating the lower limit of renewable resources.

Subvector (l) acts as the constraining element on the renewable resources. The entries in this subvector are all generally zeros. This simply indicates that the utilization rate of the renewable resources may be less than or, at most, equal to the production rate of the same renewable resources. This constraint eliminates any possibility of over-utilization of renewable resources.

12. Submatrices (M) and (N) to complete the array.

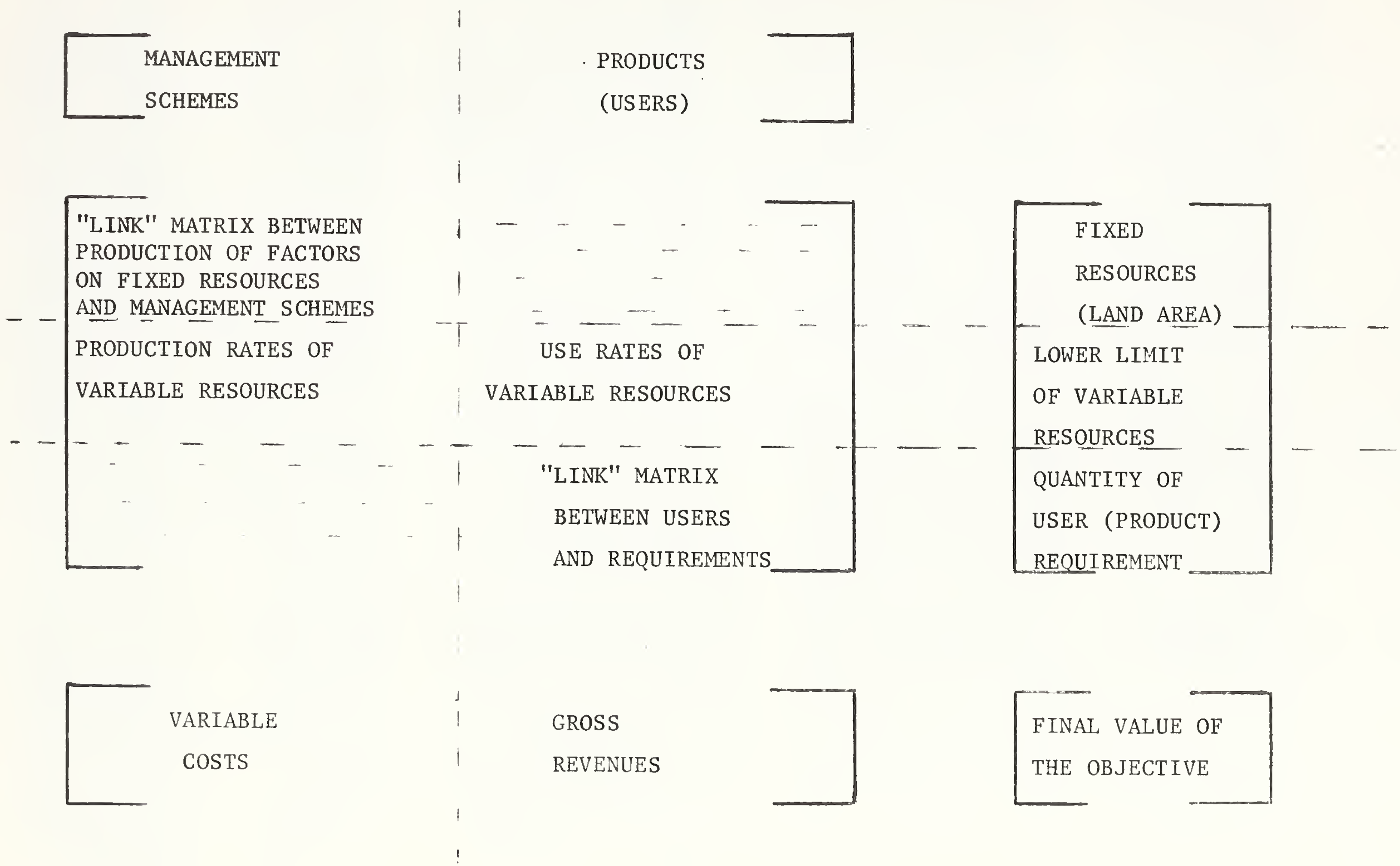
Submatrices (M) and (N) are submatrices of zeros (null matrix) to help complete the overall array of the partition notation. These null matrices perform no function in the analysis; but, are necessary to help fill in all the cells of the programming model.

13. Submatrix (Z) denoting final value of the objective.

The final element to be considered in the programming model is submatrix (Z). This submatrix may denote two differing interpretations depending on the objective of the study being considered. If the purpose of a study is to determine an optimum allocation of the resources at the least possible cost in the production of a given level of output(s); then the submatrix (Z) denotes that least-cost value. If, on the other hand, the purpose of the study is to allocate the resources in a manner that will give a level of output(s) that maximizes net revenues; then, submatrix (Z) denotes that maximum revenue value.

A summary of the vectors and matrices is shown in Figure 15. Such a system is presented here as a straight forward linear programming problem. Naturally one should realize that a suitable planning device can only use the information that is given to it. In some cases we find that decisions can be made on rather gross approximations, but by and large the better the information supplied, the better the plan. As a resource economist I have attempted to analyze and improve the "tools" available for optimum resource allocation. What is needed is a more concerted effort on the part of those involved in resource inventory to compile that "relevant" data needed for better management of resource systems.

Figure 15.


MANAGEMENT
SCHEMES
PRODUCTS
(USERS)
"LINK" MATRIX BETWEEN
PRODUCTION OF FACTORS
ON FIXED RESOURCES
AND MANAGEMENT SCHEMES
PRODUCTION RATES OF
VARIABLE RESOURCES
USE RATES OF
VARIABLE RESOURCES
"LINK" MATRIX
BETWEEN USERS
AND REQUIREMENTS
FIXED
RESOURCES
(LAND AREA)
LOWER LIMIT
OF VARIABLE
RESOURCES
QUANTITY OF
USER (PRODUCT)
REQUIREMENT
VARIABLE
COSTS
GROSS
REVENUES
FINAL VALUE OF
THE OBJECTIVE

ECOSYSTEMS DYNAMICS AND ECONOMIC DECISION

E. T. BARTLETT

The resource allocation model presented by Dr. D'Aquino is a useful model; however it incorporates two major assumptions. First, the average conditions affecting a manager do not change over time; and second, there are no fluctuations about this average. My main discussion will concern the first assumption. In order to more fully understand the relationship of these assumptions to resource models we will first define some terminology which is used by researchers.

The first assumption deals with dynamics, or the change of states through time. By making this assumption, the system is said to be static or constant through time. To illustrate this concept consider a particular range ecosystem, say a particular pasture in the short grass prairie. In the static model, we assume that the useable forage production is constant. A dynamic model, on the other hand, would allow for changes through time in the amount of useable forage, and hopefully more adequately represent the real situation and provide managers with a better tool. To summarize, static implies that there are no trends in system conditions and dynamic implies there are trends. Thus a dynamic model accounts for trends over time while a static model does not.

The second assumption that was made in the model presented by Dr. D'Aquino deals with variation about the trend of system conditions. In his model, he assumed that the state of the system was exactly known at any point in time. While this in many instances is a useful and necessary assumption, it of course does not allow a model to actually represent the real world. A model which includes this assumption is said to be deterministic. Thus Dr. D' Aquino presented a deterministic static model. A stochastic model is an abstraction that allows the average to vary with given probabilities. In our example, the amount of useable forage can be varied if the probability distribution is known and can be estimated.

The types of models that result from the two assumptions are summarized in Figure 1. The deterministic static model has been discussed. The deterministic dynamic model will be discussed during the remainder of this session. The other two models shown in Figure 1 are also linear but deal with subjects beyond the scope of our discussion.

SERIAL LINEAR MODEL

In the availability of range forage, there are seasonal fluctuations or trends during the year, and decision makers must decide when to use their forage. In the deterministic, static model, the forage was used indirectly by using the acre of range on which it was produced. However, if the land was used during a particular season, it could not be used again, that is to say any regrowth was wasted. Consequently, it is

		Trend	Average
		Static	Dynamic
Variation of Average	Deterministic	D' Aquino Linear Model	Serial Linear Model
	Stochastic	Linear Model with Monte Carlo technique	Chance-constrained Serial Model

Figure 1: Resource Allocation Model Classification

desirable to develop a model that allows this resource, forage, to flow from one season to the next. If this is done, the model is no longer static but dynamic.

In order to meet the objective of allowing forage to flow, we will first introduce a linear reservoir operation model, which utilizes a difference or discrete continuity equation. Figure 2 presents a schematic drawing of a reservoir. The decision maker must decide how to operate this system. Because this is a deterministic model, the states or conditions that are assumed to be known with certainty are the inflows into the reservoir, the initial storage and the target or ending storage.

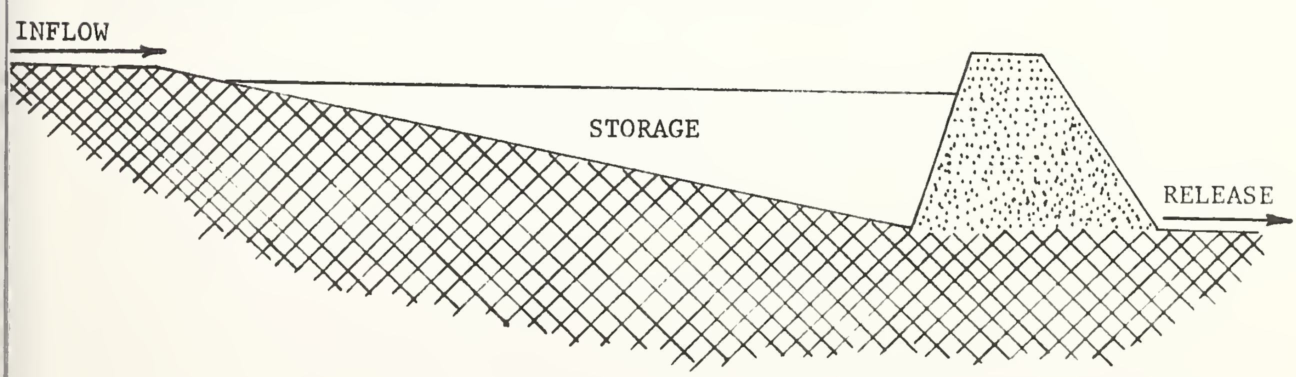


Figure 2: Schematic of a Reservoir

The decision variables of this model concern the release from the reservoir. Let us suppose that the manager wants to determine the optimal operation of the reservoir over the next four time periods, has an initial storage of 20 units and must have at least 30 units remaining in storage at the end of the fourth period. As yet we have not specified any value of release or objective function. Before we do, let us set up a constraining set of equations.

A set of equations can be formulated from the difference equation given in equation (1). This equation merely states that the change in storage over some time period (ΔS_t) is the inflow (I_t) minus the release during that period (R_t). By substituting for ΔS_t, we obtain

$$\Delta S_t = I_t - R_t \tag{1}$$

equation (2) which can be written as (3)

$$S_{t+1} - S_t = I_t - R_t \tag{2}$$

$$S_t + I_t - R_t = S_{t+1} \tag{3}$$

where S_t is the storage at the start of period t, or initial state, and S_{t+1} is the storage at the start of period t+1, or the final state in period t. Since this is a deterministic model, the inflows are assumed to be known. Let inflow be equal to 40, 30, 10, and 30 units during time period 1, 2, 3 and 4 respectively; then by applying equation (3) to each time period we obtain the linear set of equations (4)

$$\begin{aligned} S_1 + I_1 - R_1 &= S_2 \\ S_2 + I_2 - R_2 &= S_3 \\ S_3 + I_3 - R_3 &= S_4 \\ S_4 + I_4 - R_4 &\geq S_T \end{aligned} \tag{4}$$

and by substituting initial and target storage and the inflows, the constraint set becomes that shown in (5) and (6)

$$\begin{aligned} 20 + 40 - R_1 &= S_2 \\ S_2 + 30 - R_2 &= S_3 \\ S_3 + 10 - R_3 &= S_4 \\ S_4 + 30 - R_4 &\geq 30 \end{aligned} \tag{5}$$

or

$$
\begin{array}{lllllllll}
S_2 & & & + R_1 & & & & = & 60 \\
-S_2 & + S_3 & & & + R_2 & & & = & 30 \\
 & - S_3 & + S_4 & & & + R_3 & & = & 10 \\
 & & S_4 & & & & - R_4 & \geq & 0
\end{array} \qquad (6)
$$

If we now specify that release and storage can not be negative and that the objective is to maximize utility from the release where utility is 4, 6, 10, and 5 through periods 1 through four, we have a solvable linear programming formulation. The solution to this problem is shown in Table 1.

Table 1. Objective function and solution of Reservoir Example

Variable	S_2	S_3	S_4	R_1	R_2	R_3	R_4
Objective function	0	0	0	4	6	10	5
Solution	60	90	0	0	0	100	0

Because water is a flow resource, similar systems of equations can be written for other flow resources and in fact any resource that may change from one period to the next. This is the importance of the reservoir problem. Let us apply equation (3) to range forage.

$$SC_t + G_t - C_t = SC_{t+1} \qquad (7)$$

where SC_t is standing crop of forage at the start of season t, G_t is growth during season t and C_t is consumption during season t. All these variables can be expressed as pounds of forage on a particular range type. For a four season year, the set of equations (8) is developed.

$$
\begin{aligned}
SC_1 + G_1 - C_1 &= SC_2 \\
SC_2 + G_2 - C_2 &= SC_3 \\
SC_3 + G_3 - C_3 &= SC_4 \\
SC_4 + G_4 - C_4 &\geq SC_T
\end{aligned} \qquad (8)
$$

The values of C's, SC_2, SC_3, SC_4 are determined by the model. Growth rates and initial and target standing crop must be determined before the model is used. If we now rewrite the equations (8) so that variables to be determined by the model are on the left and known variables are on the right, the following system of equations is obtained.

$$
\begin{array}{llllll}
SC_2 & & & + C_1 & = & SC_1 + G_1 \\
-SC_2 & + SC_3 & & + C_2 & = & G_2 \\
 & SC_3 & + SC_4 & + C_3 & = & G_3 \\
 & & SC_4 & - C_4 & \geq & SC_T - G_4
\end{array} \qquad (9)
$$

Now that a system of linear equations has been developed to allow flows from one season to another, the deterministic static model is adjusted so that these equations are included. In that model the upper portion of the right hand side included acreage constraints for the range type. In the deterministic dynamic model we will call a "serial" linear program, the acreage constraints on range types no longer appear in this vector, but are entered below this as constraints or the pounds of forage that are produced on each type as shown in the system of equations (9). The amounts can be estimated from existing data where it exists. Where data does not exist it must either be collected or simulated through an ecological model.

In the case where the model is used by private resource managers, such as ranchers, the discrete continuity equation (3) can be applied to livestock and cash flow. In public resource management, the flow equations can be adapted to other flow resources.

SCHEDULING PROBLEMS IN ECOSYSTEMS

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Scheduling projects for the development of any natural resource can be improved with only a basic understanding of the techniques. Critical Path Analysis is a methodology used for planning, scheduling and controlling a project. Perhaps the most well known and most often used techniques of the methodology are CPM (Critical Path Method) and PERT (Program Evaluation and Review Technique).

Critical Path Analysis

The basic idea of critical path analysis is to regard the relations of all the jobs that must be accomplished in a project as a network. This network is made up of arrows that represent individual jobs or activities. The arrows are arranged in the logical sequence in which these jobs must be carried out.

When the logical network planning is complete, the next step is to assign the time required to complete each individual activity. Critical Path Analysis of this simple network then provides:

1. The longest sequence of activities from the beginning to the end of the project. This is the critical path, and
2. The amount of idle time associated with non-critical activities.

The critical path is defined as that path through the network which requires the longest duration of time to complete. The particular sequence of jobs along this path control the duration of the entire project. Therefore, if there is a delay in any one of the jobs along this path, there is a corresponding delay in completing the project. Likewise, if the project is to be completed in any less time, time can only be gained by shortening the duration of any of the activities on the critical path. The fundamental basis of critical path analysis is the network diagram. This network is a graphical model of the entire project and shows each step (job, activity or operation) and the relation between steps. The network is the vehicle used to force the planner to clearly define each activity and its relation to all others. This is the most important aspect of either CPM or PERT. The network is made up of arrows and will be called an arrow diagram. The rules for constructing an arrow diagram are as follows:

1. Each activity is shown by a single arrow and must have a definite beginning (tail of arrow) and ending (head of arrow).
2. The flow of activities is from left to right (convention).
3. The arrows are drawn to indicate preceeding, succeeding and concurrent activities.
4. The network must be continuous without any gaps.
5. Dummy arrows are used to represent logic.
6. No loops in the network are permissible.
7. For identification, circles are drawn at the tail and head of an arrow.

The arrow diagram to which circles have been added has further implications. The arrows represent the activities, operations, or jobs which require <u>time</u> for completion. The circles represent <u>events</u> or instants in time that mark the completion of a sequence of activities. Traditionally CPM is considered to be activity-oriented, while PERT is regarded as being event-oriented.

CPM (Critical Path Method)

To the completion of the network diagram, CPM and PERT are different only in the interpretation of the network. This difference is only a point of view. However, after the network is complete, the next step is assigning durations to the activities. This is the traditional departure between CPM and PERT.

CPM is a variant method of general Critical Path Analysis for planning, scheduling, and analyzing projects that have been done repeatedly and for which the durations of the activities are known with essentially no uncertainty. An example would be building a house. Activity durations are arrived at from experience and consideration of the kind of work, working conditions, tools and equipment available, worker's skill, degree of supervision, etc. Duration is figured simply by dividing man-days by the crew size for jobs involving labor.

Tips for assigning durations for CPM estimates appear below:

1. Assume a normal level of labor, equipment and other resources.
2. Ignore conflicting labor and equipment demands.
3. Consider each activity isolated from the network.
4. Assign the durations without a calendar in front of you.
5. Do not consider contingencies such as floods, fires, etc.
6. Dummy activities have zero durations.

PERT (Program Evaluation and Review Technique)

PERT is a variant of critical path methodology that is useful for planning, scheduling, and analyzing projects that have never been undertaken before and necessarily involve considerable uncertainty in assigning the duration of activities. Three estimates of activity duration are required for PERT. These are the optimistic, the most likely and the pessimistic times. Using these three estimates of time, the activities most probable time, or the expected duration is calculated.

Optimistic. The optimistic time is the record time in which an activity could be completed. The optimistic time is that time that would be bettered only one time out of twenty.

Most Likely. The most likely time is that duration that would be expected to occur most frequently, not the mean time, but the modal duration.

Pessimistic. The pessimistic time is the duration of the activity that would be exceeded one time in twenty.

Tips for arriving at the three time estimates appear below:

1. All estimates must be made without any regard for deadlines.
2. Estimates for activities in the network should be made by selecting the activity at random, without worrying about preceeding or suceeding activities.
3. Again, as in CPM, estimates should not be influenced by catastrophies such as floods, fires, etc.
4. When estimating times, assume that the same crew and resources are available under each condition (optimistic, most likely, and pessimistic).

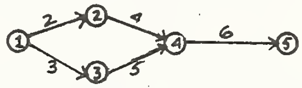
To calculate the expected activity duration, the three time estimates are assumed to be drawn from a beta distribution. For this distribution the optimistic time is A, the most likely time is M, and the pessimistic time is B. The expected activity duration is t_e and its standard deviation $s(t_e)$ are given by the following formulas:

$$t_e = \frac{A + 4M + B}{6} \qquad s(t_e) = \frac{B - A}{3.2}$$

Isolating the Critical Path

The critical path is that sequence of activities with the longest total duration. It is the chain of activities whose times determine the overall project time.

Isolating the critical path is accomplished by what is known as a forward/backward pass solution. Consider the network below.



Activities will be identified by the pair of numbers (ij), designating the tail and head of the arrow representing the particular activity. The assigned durations are marked on each arrow.

Network computations for isolating the critical path for either CPM or PERT are the same when the expected activity duration (for PERT) is regarded as a single activity duration in the table below. (CP) identifies the critical path.

Activity		Duration	Earliest		Latest		Float	
i	j		Start	Finish	Start	Finish	Total	Free
1	2	2	0	2	2	4	2	0
1	3	3	0	3	0	3	0(CP)	0
2	4	3	2	6	4	8	2	2
3	4	5	3	8	3	8	0(CP)	0
4	5	6	8	14	8	14	0(CP)	0

Rules for Forward Pass Computations

1. The initial project event is assumed to occur at time zero. The earliest start times of activities beginning with the initial event equal zero.
2. The earliest finish time of an activity is the sum of its earliest start time and its assigned duration.
3. The earliest start time of an activity is equal to the maximum early finish time of the immediately preceeding activities.

Rules for Backward Pass Computations

1. The latest finish time of the terminal project event is set equal to the earliest finish time.
2. The latest start time for an activity is equal to its latest finish time minus its duration.
3. The latest finish time for an interior activity is equal to the minimum latest start time of the immediately succeeding activities.

After the forward/backward computations are finished, two additional measures of free-time are available for each non-critical activity. These are called total float and free float. Activities on the critical path are identified by having zero total float

Total Float. Total float for an acitivty is the difference between its latest start and its earliest start.

The total float is the time or "distance" that the particular activity is away from being critical. It is the amount of time that the particular activity can be delayed without affecting the network critical path.

Free Float. Free float refers to non-critical activities. For a given activity, it is equal to the minimum earliest start of those activities succeeding it, minus its own earliest finish.

The free float of a non-critical activity is the time or "distance" that the particular activity is away from delaying an activity that succeeds it.

With CPM, results of network analysis provide the critical path and measures of float. In addition to these results, with PERT, network analysis also provides probabilities for completing an individual activity or event according to a scheduled time, t_s.

For a particular activity in a PERT network, the probability for meeting a scheduled time, t_s, for that activity is determined by looking up the corresponding probability of the Z statistic, given below:

$$Z = \frac{t_s - t_e}{s(t_e)}$$

The expected time for the event is taken as the sum of the expected times for the preceeding activities and the standard deviation for the expected time for the event is calculated by squaring and summing all the standard deviations of the preceeding activities and taking the square root of the sum. The same Z statistic is calculated and used to determine the event probability.

The present state of the art of network planning recognizes the fundamental methodology common to both CPM and PERT. While originally the two techniques were indeed different by virtue of their beginnings, they should be regarded as simply the same, but providing different results depending on the user's needs.

INTRODUCTION TO ECOSYSTEM ANALYSIS AND MODELING

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The analysis of large scale systems requires the application of various tools and techniques. Many of these tools and techniques take the form of models of the behavior of all or a portion of the system. The most important such model is that in the decision maker's head. It is on this model that decisions are made.

Decision makers generally take great pains to assure that their mental model is an "accurate" representation of the system under consideration. To improve this model, other models, conferences with experts, study and deliberation are employed. This presentation addresses one approach to the construction of "other models" that has some significant advantages in the biological arena over its competitors. The approach is based on the work of Dr. Jay W. Forrester of the Sloan Business School at M.I.T. and is, perhaps, best described in his 1961 M.I.T. Press publication, Industrial Dynamics.

This book presents, in quite readable terms, an approach to the analysis of an economic firm (and the organization on which it depends) which has many points to recommend it:

1. It is easily adapted to biological problems in spite of its development for industrial purposes.
2. It can be used by the relative novice while allowing the expert adequate flexibility to use his skills.
3. It is easily described, and specific applications are easily and naturally presented.

The approach begins with the development of a material and information flow diagram based on the modeling objectives. Using the flow diagram the modeler can "divide and conquer" in that each compartment and flow can be studied (relatively) separately and the appropriate expertise brought to bear. Having described (often in very simple mathematical terms) the flows in the system, the modeler is prepared to code the system for computer operation. The coded system is (or should be) capable of taking an initial description of the system (initial conditions) and determining the (simulated) state of the system at some later time. This later state can depend on external effects (driving variables) which are not a part of the modeled system.

This ability to simulate the state of the system at a future time based on past observations and external forces is an important characteristic of these models. Managers may test alternative policies to compare and contrast the benefits of these policies. These comparisons in the simulated environment may take only hours as compared to weeks or years to make the same comparison on the actual system. Indeed policies may be tried in the

simulated system which, because of risks or costs might never be tried in the real system.

As important as this "predictive" feature of the simulation is, it is often less so than the results of tests of system hypotheses, determination of points of system sensitivity, location of areas within the system where data and information are severely lacking. While these latter points are somewhat harder to appreciate than the predictive one, without applying this technique they are no less (often more) significant.

This approach has now been applied to a variety of biological and biological/management problems. A few of these will be described briefly below:

1. Lodgepole Pine Simulator

This model has been developed by Mr. Bob Woodmansee as part of his doctoral dissertation. It contains two major submodels - a biomass model and a potassium model. In the biomass model the dynamics of growth, death, and decay of the lodgepole pine stand is subdivided into needles (by age class), twigs, stems (boles), cones, roots and litter. The growth functions involved are taken from literature, personal observation, and intuition. In the nutrient model, the potassium content of each of the biomass compartments as well as that of the soil (A and B horizons), rain and weather input and leach and erosion output are considered. The potassium reserves control growth rates (if limiting) and growth controls potassium use rates.

The model has been used to compare 3 management regimes: a) "natural" with wildfires occurring each 70 years, b) clearcut with slash left to decay each 70 years, and c) clearcut with slash removal each 70 years. By adjusting certain parameters so that the system is stable in the natural system, comparisons of the two clearcut regimes can be made. The simulation indicates that net potassium losses under treatment b are less than that of c and greater than that of a; it indicates that these losses would significantly effect growth rates by the third cycle (years 140 to 210); it also indicates that effective fertilization in small amounts would largely eliminate these losses.

On the other hand the model is simplistic. Many important effects are treated superficially - others are estimated where data are absent. Variations of parameters well within our uncertainty of their value make large differences in the conclusions. The greatest benefit derived thus far is to focus our attention on those aspects of the system where our knowledge is weak and the system is sensitive.

2. Tropical Forest Simulator

This model is similar to the previous one but is more detailed and involved. There is a biomass subsystem that treats forest and domestic crop growth (following a slash and burn). Four nutrients (phosphorus, potassium, calcium and magnesium) are studied and the interactions between the biomass and nutrient subsystems are included.

There is less known about a given forest area in the tropical system than for the lodgepole pine. It results that data are taken from a variety of sources and welded together. This process can be questioned in many cases. Still one can demonstrate that regrowth is nutrient limited; that repeating the slash and burn requires longer each cycle before the system has recovered enough to make the effort economical; and that research is needed in certain specific areas in order to effectively manage these systems.

3. Grassland Model

The USIBP Grassland Biome Program has constructed several models of grassland systems. One of them, ELM, is written in the Forrester style. This model is quite large and elaborate. The major subdivisions are abiotic (heat, water and light), producer (several species and several compartments per species), consumer (energetics and diet selection), decomposer and nutrient (nitrogen and phosphorus). The current version has 70+ compartments (state variables), 200+ flows (processes) and many parameters. This model has been developed to help manage the program and later to help manage grassland systems. We are concerned with gaining a thorough knowledge of ecosystem dynamics and the model is an excellent place to test the consistency of the biological hypotheses being developed about the system components. Once this "thorough knowledge" is obtained [wow!] the model will embody at least a part of that knowledge and will be useful in testing management policies for benefits and for consistency with the ecological system. We are far from fully realizing this latter goal although we are now able to address and answer certain subsystem questions of a management nature.

Many other examples could be given of progress in using systems analysis in the study of biological and ecological systems. These three suffice here to illustrate the point and to indicate the state of the art.

It should be reiterated that the use of systems analysis techniques in ecosystem studies is relatively new. We are still using engineering and physics tools without developing more suitable tools designed for biological problems. These newer tools are coming as the needs for them are determined. In the meantime much can be done with the tools at hand.

DRIVING VARIABLES OF THE ECOSYSTEM

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Climate and life at the earth's surface have been closely linked since the beginning of geological time 600 million years ago. This link is so strong that we often use species location and abundance preserved in fossils as indications of past climate. This geological evidence indicates that most modern day geographical locations have had past climates vastly different from that which they enjoy today. For example, fossil evidence of tropical vegetation and animal species have been found in the Rocky Mountain States as well as in the Antarctic. In this lecture I shall discuss the climate as a forcing function on the biosphere in as much as the climate determines the energy and water budgets available to support life in the biosphere. I shall also discuss how man has changed and may in the future alter the climate, either intentionally or inadvertently.

When we speak of climate in the biosphere we generally refer to the temperature, wind, moisture and radiation conditions in the lowest few meters of the atmosphere. While we must consider all of these components for a true picture of the climate, (see fig. 1) it is usually necessary to simplify the picture by looking only at one or two components at a time. In fig. 2, you see plotted "climograms" for four different geographical locations in the United States. Each trace is characteristic of a different climate regime and you should be able to relate your knowlege of climate variation to these profiles. Fig. 3 shows a similar comparison of the annual temperature and moisture conditions which various flora may tolerate. Detailed inspection of the monthly distribution of moisture will assist in interpreting the areas of overlap in fig. 3. You may take data from Tables 1 and 2 and validate the flora distribution predicted by fig. 3, against your own knowledge.

From your own experience, or by looking out the window to the west, one recognizes that different flora are found on a north facing slope than on a south facing slope. What microclimate factors may be responsible for this difference? Let us refer back to fig. 1. Certainly the solar radiation is different on the two slopes and this would cause a difference in temperature. One would not necessarily expect the precipitation to be significantly different unless there is a significant orographic effect. However, the south facing slope would receive substantially more sunshine and would tend to dry out faster, thus having a more restrictive moisture budget. On an east-west slope comparison, prevailing winds may play a role in determining vegetation distribution both through the physical battering of vegetation and through the wind's interaction in the energy and moisture budget of an area. Trees on exposed ridges near treeline are examples of a wind-related climate restriction.

Another example of complicated interaction between vegetation and climate conditions is the 1970 corn blight occurrence in the midwestern U.S. In July, a fungus, the southern corn leaf blight, mutated into a form which attacked a new, widely used hybrid corn. While corn blight

outbreaks were not uncommon in the southern states, it had not been previously detected in the northern midwest states. Unusually persistent winds from the south advected warm humid air from the Gulf of Mexico into the upper midwest. This air flow served two purposes for the corn blight fungus. It transported spores northward from previously infected fields and it advected warm moist air essential to the growth of the fungus. Fields of corn would change from a healthy condition to a total loss in a time span of two or three days. This is an illustration of how vegetation and climate interact through another mechanism, that of disease.

So far we have been concerned with temperature and moisture limitations on flora. Next let us examine the restrictive climate regimes for animals. Precipitation is not as critical in this case since the animal can move to natural storage reservoirs for his water. Instead of the temperature - moisture climate space in fig. 2, we construct a temperature - absorbed radiation climate space, fig. 4. I have depicted the climate space for two animals, a desert dwelling iguana and a bird, the cardinal. In words, this climate space tells us the conditions under which this species can survive. Values to the upper right of the quadralateral would result in the animal becoming overheated; values to the lower left would result in too great an energy loss for the animal's metabolism to make up for, thus its body temperature would drop.

Next, let us turn to climate modification. I am not speaking of global climate and longterm changes in global temperature but of changes of local microclimate which man is definitely capable of accomplishing. Probably the most well known microclimate modification is the greenhouse where one may control virtually all the climate variables shown in fig. 1. But instead of limiting ourselves to microclimate modification of an area of a few square yards, let us look at areas the size of a watershed or a state.

Irrigation of cropland is a form of climate modification known to all of us. In essence, by augmenting the water supply, we skew the curve shown for Denver in fig. 2, to the right during the summer months. This makes it possible to grow corn which requires a minimum annual rainfall of 25 inches instead of wheat which requires only 15 inches annual rainfall.

Seeding of orographic clouds in order to produce greater wintertime precipitation has been studied by Professor L.O. Grant of CSU, and is presently being done operationally by the Bureau of Reclamation in the Wolf Creek Pass area. The physical principle behind this cloud seeding is that at temperatures warmer than about -24°C there is generally a deficit of natural ice nuclei in the air. By adding additional ice nuclei one makes possible more hydrometeors which will fall out as snow. On the other hand, at temperatures colder than -24°C, there is generally an abundance of natural ice nuclei and addition of more ice nuclei may actually lessen the amount of precipitation by making many small hydrometeors which do not fall out on the windward side of the slope producing the orographic lifting.

A classic example of man's activity inadvertently causing a climate change is the Rajasthan Desert in northwestern India - a man-made desert. Historical and archeological evidence indicate that around 400 B.C. this same area was a thriving agricultural region. Today it is desert! What is there to explain an arid desert when similar temperature and moisture conditions elsewhere support agriculture? Fig. 5, illustrates the sequence of events leading to the establishment of this arid region.

Let me mention two processes essential to understanding the evolution of this man-made desert. First, minimum nocturnal temperatures are found to be lower over a grass surface than over an adjacent compacted soil surface. This is evidenced by the fact that on a cool autumn morning one can see frost on grass while adjacent pavement or soil is dry. Second, dust in the first several kilometers of the atmosphere tends to increase the infrared cooling of the layer thus causing a general subsidence, or sinking motion.

Not let us return to the desert evolution problem. What was once a succulent grassland region was initially overgrazed by goats and sheep which are still common in this areas. With bare soil exposed minimum nocturnal temperatures did not reach the dew point and grasses were not able to replenish soil moisture by inverse evapotranspiration. With the soil thusly denuded of vegetation, the wind eroded the soil lifting quantities of dust into the atmosphere. This dust caused increased infrared cooling and general sinking motion of the air, but cloud formation and rain require upward motion of air. Therefore, the radiation-induced subsidence tends to suppress cloud and rain formation. Less rain tends to make the surface dustier and more susceptible to soil erosion by the wind. This in turn enhances the infrared cooling and on and on. We are caught in a positive feedback loop where the dust causes infrared cooling and the infrared cooling, by supressing precipitation, causes more dust.

In summary, climate affects the biosphere in many ways. These interactions may be very straight forward. For example, in the absence of light, photosynthesis will not occur. They may be very complex as in the case of the corn blight. The principal climate variables impacting on the biosphere are temperature, moisture, wind and radiation. These parameters determine the energy and water budgets which constrain all life.

Man has the ability to modify climate; simple examples are windbreaks and irrigation. More complex climate modification such as cloud seeding appears feasible in the near future. However, man must be very careful to understand all ramifications of his climate modification activities lest he produce undesirable, irreversible results. This does not mean we should not be progressive, only that we be thorough.

TABLE 1

TABLE 1-4. NORMAL MONTHLY AVERAGE TEMPERATURE– SELECTED CITIES OF THE UNITED STATES

(Source: Environmental Science Services Administration)

[In Fahrenheit degrees. Airport data unless otherwise noted. Based on standard 30-year period, 1931 to 1960]

STATION		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual avg.
Ala . .	Mobile	53.0	55.2	60.3	67.6	75.6	81.5	82.6	82.1	77.9	69.9	58.9	54.1	68.2
Alaska	Juneau	25.1	26.8	30.4	38.0	45.6	52.3	55.3	54.1	48.9	41.6	34.3	28.4	40.1
Ariz .	Phoenix	49.7	53.5	59.0	67.2	75.0	83.6	89.8	87.5	82.8	70.7	58.1	51.6	69.0
Ark . .	Little Rock	40.6	44.4	51.8	62.4	70.5	78.9	81.9	81.3	74.3	63.1	49.5	41.9	61.7
Calif .	Los Angeles	54.4	55.2	57.0	59.4	62.0	64.8	69.1	69.1	68.5	64.9	61.1	56.9	61.9
	Sacramento	45.2	49.2	53.4	58.4	64.0	70.5	75.4	74.1	71.6	63.5	52.9	46.4	60.4
	San Francisco[1]	50.7	53.0	54.7	55.7	57.4	59.1	58.8	59.4	62.0	61.4	57.4	52.5	56.8
Colo .	Denver	28.5	31.5	36.4	46.4	56.2	66.5	72.9	71.5	63.0	51.4	37.7	31.6	49.5
Conn.	Hartford	26.0	27.1	36.0	48.5	59.9	68.7	73.4	71.2	63.3	53.0	41.3	28.9	49.8
Del . .	Wilmington	33.4	33.8	41.3	52.1	62.7	71.4	76.0	74.3	67.6	56.6	45.4	35.1	54.1
D.C. .	Washington	36.9	37.8	44.8	55.7	65.8	74.2	78.2	76.5	69.7	59.0	47.7	38.1	57.0
Fla . .	Jacksonville	55.9	57.5	62.2	68.7	75.8	80.8	82.6	82.3	79.4	71.0	61.7	56.1	69.5
	Miami	66.9	67.9	70.5	74.2	77.6	80.8	81.8	82.3	81.3	77.8	72.4	68.1	75.1
Ga . .	Atlanta	44.7	46.1	51.4	60.2	69.1	76.6	78.9	78.2	73.1	62.4	51.2	44.8	61.4
Hawaii	Honolulu	72.5	72.4	72.8	74.2	75.9	77.9	78.8	79.4	79.2	78.2	75.9	73.6	75.9
Idaho	Boise	29.1	34.5	41.7	50.4	58.2	65.8	75.2	72.1	62.7	51.6	38.6	32.2	51.0
Ill . . .	Chicago	26.0	27.7	36.3	49.0	60.0	70.5	75.6	74.2	66.1	55.1	39.9	29.1	50.8
	Peoria	25.7	28.4	37.6	50.8	61.5	71.7	76.0	74.3	66.4	55.3	39.7	29.1	51.4
Ind . .	Indianapolis	29.1	31.1	38.9	50.8	61.4	71.1	75.2	73.7	66.5	55.4	40.9	31.1	52.1
Iowa .	Des Moines	19.9	23.4	33.8	48.7	60.6	71.0	76.3	74.1	65.4	54.2	37.1	25.3	49.2
Kans .	Wichita	32.0	36.3	44.5	56.7	66.0	76.5	80.9	80.8	71.3	59.9	44.4	35.8	57.1
Ky . .	Louisville	35.0	35.8	43.3	54.8	64.4	73.4	77.6	76.2	69.5	57.9	44.7	36.3	55.7
La . .	New Orleans	54.6	57.1	61.4	67.9	74.4	80.1	81.6	81.9	78.3	70.4	60.0	55.4	68.6
Maine	Portland	21.8	22.8	31.4	42.5	53.0	62.1	68.1	66.8	58.7	48.6	38.1	25.8	45.0
Md . .	Baltimore	34.8	35.7	43.1	54.2	64.4	72.5	76.8	75.0	68.1	57.0	45.5	35.8	55.2
Mass .	Boston	29.9	30.3	37.7	47.9	58.8	67.8	73.7	71.7	65.3	55.0	44.9	33.3	51.4
Mich.	Detroit	26.9	27.2	34.8	47.6	59.0	69.7	74.4	72.8	65.1	53.8	40.4	29.9	50.1
	Sault Ste. Marie	15.8	15.7	23.8	38.0	49.6	59.0	64.6	64.0	55.8	46.3	33.3	20.9	40.6
Minn	Duluth	8.7	10.8	21.3	37.0	49.2	58.8	65.5	63.8	54.2	44.6	27.3	14.0	37.9
	Minneapolis-St. Paul	12.4	15.7	27.4	44.3	57.3	66.8	72.3	70.0	60.4	48.9	31.2	18.1	43.7
Miss .	Jackson	47.9	50.5	56.5	64.9	73.1	79.8	82.3	82.0	76.5	67.0	55.5	49.4	65.5
Mo . .	Kansas City	31.7	35.8	43.3	55.7	65.6	75.9	81.5	79.8	71.3	60.2	44.6	35.8	56.8
	St. Louis	31.9	34.7	42.6	54.9	64.2	74.1	78.1	76.8	69.5	58.4	44.1	34.8	55.3
Mont	Great Falls	22.1	23.8	30.7	43.6	53.0	59.9	69.4	66.8	57.4	47.5	34.3	27.3	44.7
Nebr .	Omaha	22.3	26.5	36.9	51.7	63.0	73.1	78.5	76.2	66.9	55.7	38.9	28.2	51.5
Nev . .	Reno	30.4	35.6	41.5	48.0	53.9	60.1	67.7	65.5	58.8	49.2	38.3	31.9	48.4
N.H .	Concord	21.2	22.7	31.7	43.8	55.5	64.5	69.6	67.4	59.3	48.7	37.6	25.0	45.6
N.J. .	Atlantic City	34.8	34.7	41.1	51.0	61.3	70.0	75.1	73.7	67.2	57.2	46.7	36.6	54.1
N.Mex	Albuquerque	35.0	39.9	45.8	55.7	65.1	74.9	78.5	76.2	70.0	58.0	43.6	37.0	56.6
N.Y. .	Albany	22.7	23.7	33.0	46.2	57.9	67.3	72.1	70.0	61.6	50.8	39.1	26.5	47.6
	Buffalo	24.5	24.1	31.5	43.5	54.8	64.8	69.8	68.4	61.4	50.8	39.1	27.7	46.7
	New York[1]	32.2	33.4	40.5	51.4	62.4	71.4	76.8	75.1	68.5	58.3	47.0	35.9	54.5
N.C. .	Charlotte	42.7	44.2	50.0	60.3	69.0	77.1	79.2	78.7	72.9	62.5	50.4	42.7	60.8
	Raleigh	41.6	43.0	49.5	59.3	67.6	75.1	77.9	76.9	71.2	60.5	50.0	41.9	59.5
N.Dak	Bismarck	9.9	13.5	26.2	43.5	55.9	64.5	71.7	69.3	58.7	46.7	28.9	17.8	42.2
Ohio	Cincinnati[1]	35.5	36.8	44.3	55.7	65.8	75.3	78.8	77.4	70.6	59.5	46.4	37.2	56.9
	Cleveland	27.5	27.6	35.4	46.6	57.5	67.2	71.5	69.9	63.4	52.8	40.4	29.9	49.2
	Columbus	29.9	31.1	38.9	50.8	61.5	70.8	74.8	73.2	65.9	54.2	41.2	31.5	52.0
Okla .	Oklahoma City	37.0	41.3	48.5	59.9	68.4	78.0	82.5	82.8	73.8	62.9	48.4	40.3	60.3
Oreg .	Portland	38.4	42.0	46.1	51.8	57.4	62.0	67.2	66.6	62.2	54.2	45.1	41.3	52.9
Pa . . .	Philadelphia	32.3	33.2	41.0	52.0	62.6	71.0	75.6	73.6	66.7	55.7	44.3	33.9	53.5
	Pittsburgh	28.9	29.2	36.8	49.0	59.8	68.4	72.1	70.8	64.2	53.1	40.8	30.7	50.3
R.I. . .	Providence	29.2	29.7	37.0	47.2	57.5	66.2	72.1	70.5	63.2	53.2	43.0	32.0	50.1
S.C. .	Columbia	46.9	48.4	54.4	63.6	72.2	79.7	81.6	80.5	75.3	64.7	53.7	46.4	64.0
S.Dak	Sioux Falls	15.2	19.1	30.1	45.9	58.3	68.1	74.3	71.8	61.8	50.3	32.6	21.1	45.7
Tenn	Memphis	41.5	44.1	51.1	61.4	70.3	78.5	81.3	80.5	73.9	63.1	50.1	42.5	61.5
	Nashville	39.9	42.0	49.1	59.6	68.6	77.4	80.2	79.2	72.8	61.5	48.5	41.4	60.0
Tex . .	Dallas	45.9	49.5	56.1	65.0	72.9	81.3	84.9	85.0	77.9	67.8	54.9	48.1	65.8
	El Paso	42.9	49.1	54.9	63.4	71.9	81.0	81.9	80.4	74.5	64.4	51.2	44.1	63.3
	Houston	53.6	55.8	61.3	68.5	76.0	81.6	83.0	83.2	79.2	71.4	60.8	55.7	69.2
Utah .	Salt Lake City	27.2	32.5	40.4	49.9	58.9	67.4	76.9	74.5	64.4	51.7	36.7	30.1	50.9
Vt . .	Burlington	16.2	17.4	26.7	41.2	53.8	64.2	69.0	66.7	58.4	47.6	35.3	21.5	43.2
Va .	Norfolk	41.2	41.6	48.0	58.0	67.5	75.6	78.8	77.5	72.6	62.0	51.4	42.5	59.7
	Richmond	38.7	39.9	47.7	58.1	67.0	75.1	78.1	76.0	70.2	58.7	48.5	39.7	53.1
Wash	Seattle-Tacoma	38.3	40.8	43.8	49.2	55.5	59.8	64.9	64.1	59.9	52.4	43.9	40.8	51.1
	Spokane	25.3	30.0	38.1	47.3	56.2	61.9	70.5	68.0	60.9	49.1	35.7	30.1	47.8
W. Va.	Charleston	36.6	37.5	44.4	55.3	64.8	72.0	74.9	73.8	68.2	57.3	45.3	37.1	55.6
Wis . .	Milwaukee	20.6	22.4	31.0	43.6	53.4	63.3	68.7	67.8	60.3	50.0	35.8	24.6	45.1
Wyo .	Cheyenne	25.4	27.3	32.4	42.6	52.9	63.0	70.0	67.7	58.6	47.5	34.2	29.5	45.9
P.R. .	San Juan	74.4	74.4	75.3	76.6	78.7	80.0	80.4	80.9	80.5	80.0	78.2	76.2	78.0

[1]City office data.

TABLE 2

CLIMATE AND PRECIPITATION

TABLE 1-5. NORMAL MONTHLY AND ANNUAL PRECIPITATION— SELECTED CITIES OF THE UNITED STATES

(Source: Environmental Science Services Administration)

[In inches. Airport data unless otherwise noted. Based on standard 30-year period, 1931 to 1960. T denotes trace]

STATION		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual avg.
Ala. . .	Mobile	4.64	4.59	7.23	6.36	4.88	6.23	9.67	6.44	6.25	3.03	3.35	5.46	68.13
Alaska	Juneau	4.00	3.06	3.27	2.87	3.24	3.39	4.49	5.02	6.67	8.33	6.06	4.22	54.62
Ariz.	Phoenix	0.73	0.85	0.66	0.32	0.13	0.09	0.77	1.12	0.73	0.46	0.49	0.85	7.20
Ark. .	Little Rock	5.22	4.33	4.81	4.93	5.28	3.61	3.34	2.82	3.23	2.88	4.12	4.09	48.66
Calif. .	Los Angeles	2.66	2.88	1.79	1.05	0.13	0.05	0.01	0.02	0.17	0.39	1.09	2.39	12.63
	Sacramento	3.18	2.99	2.36	1.40	0.59	0.10	T	0.02	0.19	0.77	1.45	3.24	16.29
	San Francisco	4.01	3.48	2.69	1.30	0.48	0.11	0.01	0.02	0.19	0.74	1.57	4.09	18.69
Colo.	Denver	0.55	0.69	1.21	2.11	2.70	1.44	1.53	1.28	1.13	1.01	0.69	0.47	14.81
Conn. .	Hartford	3.58	2.94	3.80	3.73	3.41	3.70	3.61	4.01	3.65	3.18	3.84	3.47	42.92
Del. . .	Wilmington	3.40	2.95	4.02	3.33	3.53	4.07	4.25	5.59	3.95	2.91	3.53	3.03	44.56
D.C. . .	Washington	3.03	2.47	3.21	3.15	4.14	3.21	4.15	4.90	3.83	3.07	2.84	2.78	40.78
Fla. . .	Jacksonville	2.45	2.91	3.49	3.55	3.47	6.33	7.08	6.85	7.56	5.16	1.69	2.22	53.36
	Miami	2.03	1.87	2.27	3.88	6.44	7.37	6.75	6.97	9.47	8.21	2.83	1.67	59.76
Ga. . .	Atlanta	4.44	4.51	5.37	4.47	3.16	3.83	4.72	3.60	3.26	2.44	2.96	4.38	47.14
Hawaii	Honolulu	3.76	3.30	2.89	1.31	0.99	0.33	0.44	0.89	0.99	1.84	2.16	2.99	21.89
Idaho	Boise	1.32	1.33	1.32	1.16	1.29	0.89	0.21	0.16	0.39	0.84	1.20	1.32	11.43
Ill. . . .	Chicago	1.86	1.60	2.74	3.04	3.73	4.07	3.37	3.16	2.73	2.78	2.20	1.90	33.18
	Peoria	1.88	1.71	2.85	3.97	4.27	4.08	3.54	2.88	3.05	2.53	2.14	1.94	34.84
Ind. .	Indianapolis	3.05	2.28	3.41	3.74	3.99	4.62	3.50	3.03	3.24	2.62	3.09	2.68	39.25
Iowa. .	Des Moines	1.30	1.10	2.09	2.53	4.07	4.71	3.06	3.67	2.88	2.06	1.76	1.14	30.37
Kans. .	Wichita	0.81	0.92	1.64	2.30	3.97	4.21	3.64	2.87	3.22	2.40	1.49	[illegible]	28.41
Ky. . .	Louisville	4.10	3.29	4.59	3.82	3.90	3.99	3.36	2.97	2.63	2.25	3.20	3.22	41.32
La. . . .	New Orleans	3.84	3.99	5.34	4.55	4.38	4.43	6.72	5.34	5.03	2.84	3.34	4.10	53.90
Maine	Portland	4.37	3.80	4.34	3.73	3.41	3.18	2.86	2.42	3.52	3.20	4.17	3.85	42.85
Md. . .	Baltimore	3.43	2.89	3.82	3.60	3.98	3.29	4.22	5.19	3.33	3.18	3.13	2.99	43.05
Mass. .	Boston	3.94	3.32	4.22	3.77	3.34	3.48	2.88	3.66	3.46	3.14	3.93	3.63	42.77
Mich. .	Detroit	2.05	2.08	2.42	3.00	3.53	2.83	2.82	2.86	2.44	2.63	2.21	2.08	30.95
	Sault Ste.Marie	2.07	1.50	1.81	2.16	2.77	3.30	2.48	2.89	3.81	2.82	3.33	2.28	31.22
Minn. .	Duluth	1.15	0.96	1.62	2.36	3.29	4.27	3.54	3.81	2.86	2.17	1.78	1.16	28.97
	Minneapolis-St. Paul	0.70	0.78	1.53	1.85	3.19	4.00	3.27	3.18	2.43	1.59	1.40	0.86	24.78
Miss. .	Jackson	5.18	4.96	5.74	4.91	4.38	3.79	4.76	3.33	2.53	2.04	3.90	5.30	50.82
Mo. . .	Kansas City	1.41	1.24	2.49	3.56	4.40	4.57	3.19	3.77	3.25	2.86	1.80	1.53	34.07
	St. Louis	1.98	2.04	3.08	3.71	3.73	4.29	3.30	3.02	2.76	2.86	2.57	1.97	35.31
Mont	Great Falls	0.61	0.74	0.92	0.98	2.10	2.90	1.28	1.26	1.20	0.73	0.75	0.60	14.07
Nebr. .	Omaha	0.82	0.95	1.45	2.56	3.48	4.53	3.37	3.98	2.63	1.73	1.26	0.80	27.56
Nev. . .	Reno	1.19	1.02	0.68	0.54	0.52	0.37	0.27	0.17	0.23	0.51	0.57	1.08	7.15
N.H. . .	Concord	3.23	2.48	3.26	3.31	3.17	3.60	3.41	2.96	3.75	2.66	3.72	3.25	38.80
N.J. . .	Atlantic City	3.56	3.13	3.91	3.41	3.51	2.83	3.72	4.90	3.31	3.20	3.66	3.22	42.36
N.Mex	Albuquerque	0.41	0.38	0.48	0.47	0.75	0.57	1.20	1.33	0.95	0.75	0.38	0.46	8.13
N.Y. .	Albany	2.47	2.20	2.72	2.77	3.47	3.25	3.49	3.07	3.58	2.77	2.70	2.59	35.08
	Buffalo	2.84	2.72	3.24	3.01	2.95	2.54	2.57	3.05	3.13	3.00	3.60	3.00	35.65
	New York[1]	3.31	2.84	4.01	3.43	3.67	3.31	3.70	4.44	3.87	3.14	3.39	3.26	42.37
N.C. . .	Charlotte	3.53	3.55	4.39	3.49	[illegible]	3.61	4.88	4.22	3.49	2.96	2.53	3.62	43.38
	Raleigh	3.22	3.23	3.35	3.52	3.52	3.70	5.49	5.20	3.85	2.71	2.77	3.02	43.58
N.Dak	Bismarck	0.44	0.43	0.78	1.22	1.97	3.40	2.19	1.73	1.19	0.85	0.59	0.36	15.15
Ohio. .	Cincinnati[1]	3.67	2.80	3.89	3.63	3.80	4.18	3.59	3.28	2.71	2.24	2.95	2.77	39.51
	Cleveland	2.67	2.33	3.13	3.41	3.52	3.43	3.31	3.28	2.90	2.42	2.61	2.34	35.35
	Columbus	3.16	2.31	3.16	3.49	4.00	4.16	3.93	2.86	2.65	2.11	2.50	2.34	36.67
Okla. .	Oklahoma City	1.31	1.37	1.97	3.12	5.19	4.47	2.37	2.52	3.02	2.51	1.56	1.41	30.82
Oreg. .	Portland	5.37	4.22	3.83	2.09	1.99	1.67	0.41	0.65	1.63	3.61	5.33	6.38	37.18
Pa. . . .	Philadelphia	3.32	2.80	3.80	3.40	3.74	4.05	4.16	4.63	3.46	2.78	3.40	2.94	42.48
	Pittsburgh	2.97	2.19	3.32	3.08	3.91	3.78	3.88	3.31	2.54	2.52	2.24	2.40	36.14
R.I. . .	Providence	3.81	3.10	4.14	3.75	3.35	2.76	2.91	3.96	3.52	3.10	4.11	3.62	42.13
S.C. . .	Columbia	3.02	3.74	4.26	4.01	3.54	3.85	6.09	5.74	4.31	2.38	2.36	3.52	46.82
S.Dak	Sioux Falls	0.62	0.93	1.54	2.31	3.38	4.35	2.84	3.59	2.61	1.25	1.00	0.74	25.16
Tenn. .	Memphis	6.07	4.69	5.07	4.63	4.23	3.68	3.54	2.97	2.82	2.72	4.38	4.93	49.73
	Nashville	5.49	4.51	5.19	3.74	3.72	3.25	3.72	2.86	2.87	2.32	3.28	4.19	45.15
Tex. . .	Dallas	2.32	2.55	2.85	4.00	4.83	3.24	[illegible]	1.93	2.82	2.70	2.70	2.67	34.55
	El Paso	0.46	0.41	0.35	0.29	0.40	0.69	[illegible]	1.19	1.14	0.85	0.33	0.49	7.89
	Houston	3.78	3.44	2.67	3.24	4.32	3.69	4.29	4.27	4.26	3.77	3.86	4.36	45.95
Utah. .	Salt Lake City	1.35	1.18	1.56	1.76	1.40	0.98	0.58	0.87	0.53	1.15	1.30	1.24	13.90
Vt. . . .	Burlington	1.95	1.79	2.11	2.63	2.99	3.49	3.85	3.37	3.31	2.97	2.62	2.13	33.21
Va. . .	Norfolk	3.33	3.21	3.45	3.16	3.36	3.61	5.92	5.97	4.22	2.92	3.05	2.74	44.94
	Richmond	3.46	2.90	3.42	3.15	3.72	3.75	5.61	5.54	3.65	3.00	3.04	2.97	44.21
Wash. .	Seattle-Tacoma	5.73	4.24	3.79	2.40	1.73	[illegible]	0.81	0.95	2.05	4.02	5.35	6.29	38.94
	Spokane	2.44	1.86	1.50	0.91	1.21	1.49	0.38	0.41	0.75	1.57	2.24	2.43	17.19
W.Va. .	Charleston	4.32	3.53	4.34	3.68	3.71	3.69	5.67	3.95	2.92	2.58	2.79	3.25	44.43
Wis. . .	Milwaukee	1.83	1.40	2.31	2.53	3.16	3.64	2.95	3.06	2.72	2.10	2.18	1.63	29.51
Wyo. .	Cheyenne	0.52	0.56	1.21	1.88	2.52	2.11	1.82	1.44	1.10	0.83	0.62	0.45	15.06
P.R. . .	San Juan	4.70	2.90	2.20	3.72	7.12	5.66	6.25	7.13	6.76	5.83	6.49	5.45	64.21

[1] City office data.

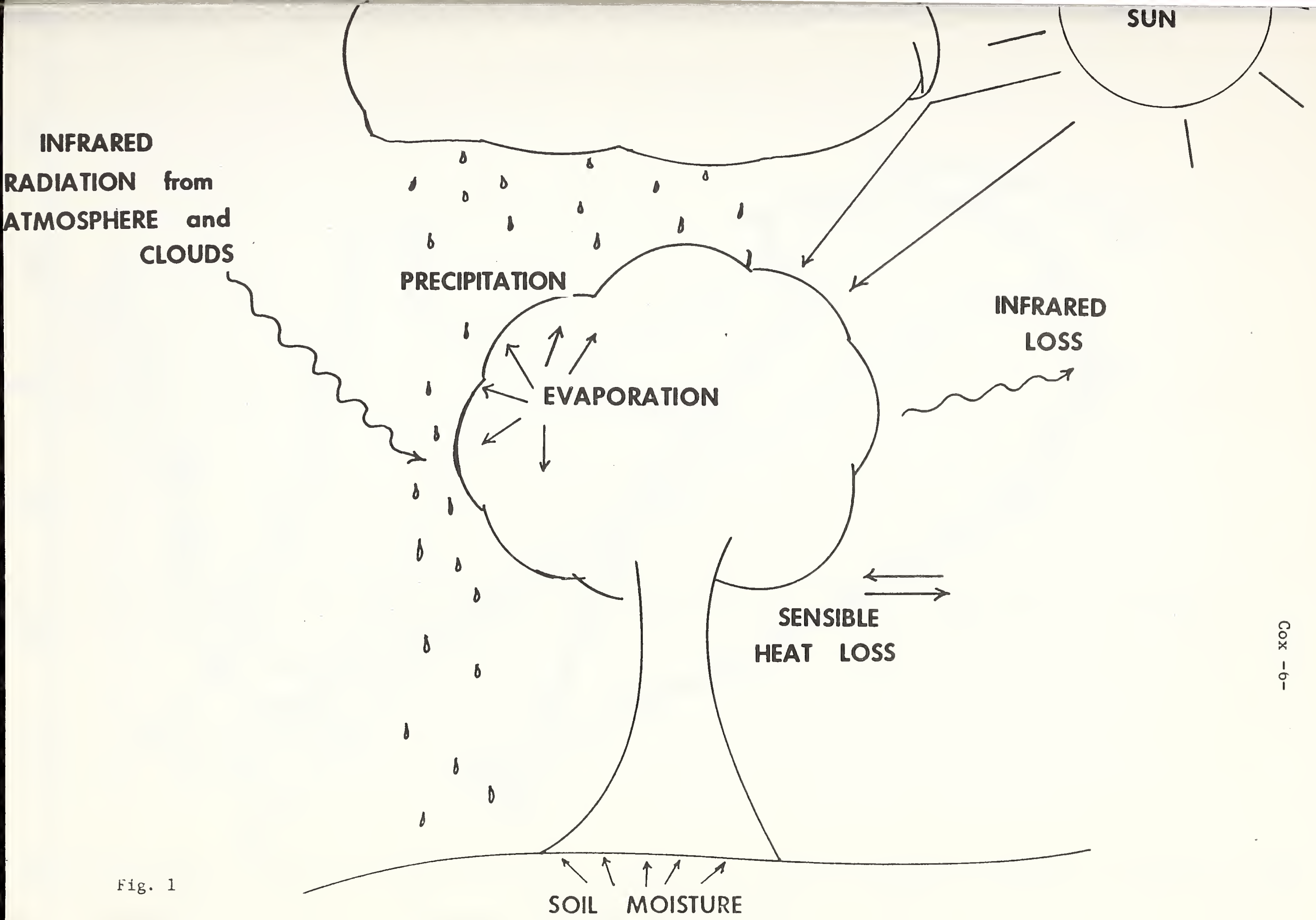
SUN
INFRARED RADIATION from ATMOSPHERE and CLOUDS
PRECIPITATION
EVAPORATION
INFRARED LOSS
SENSIBLE HEAT LOSS
SOIL MOISTURE

Fig. 1

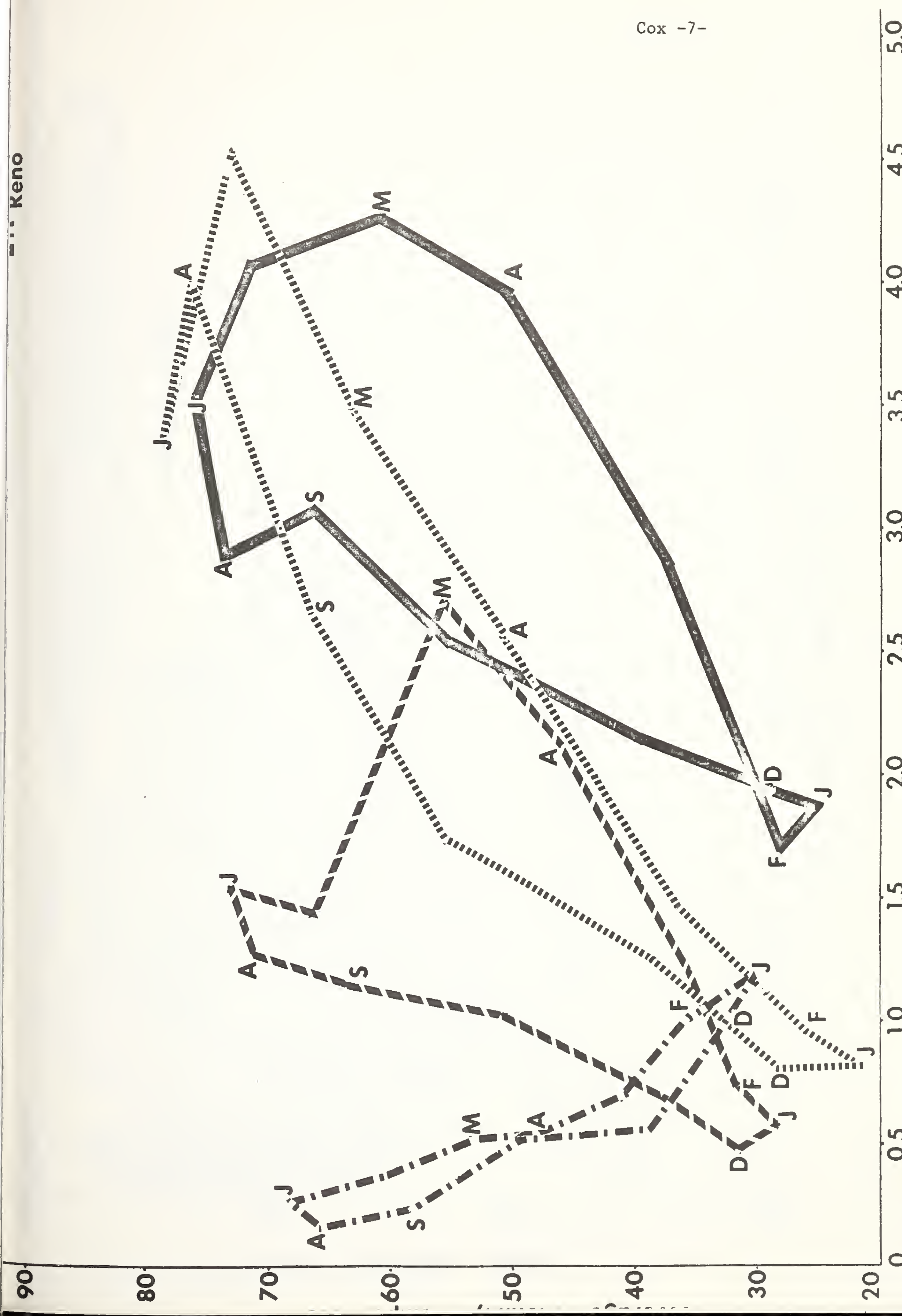
Reno
Average Monthly Precipitation , Inches
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
20
30
40
50
60
70
80
90

Fig. 2

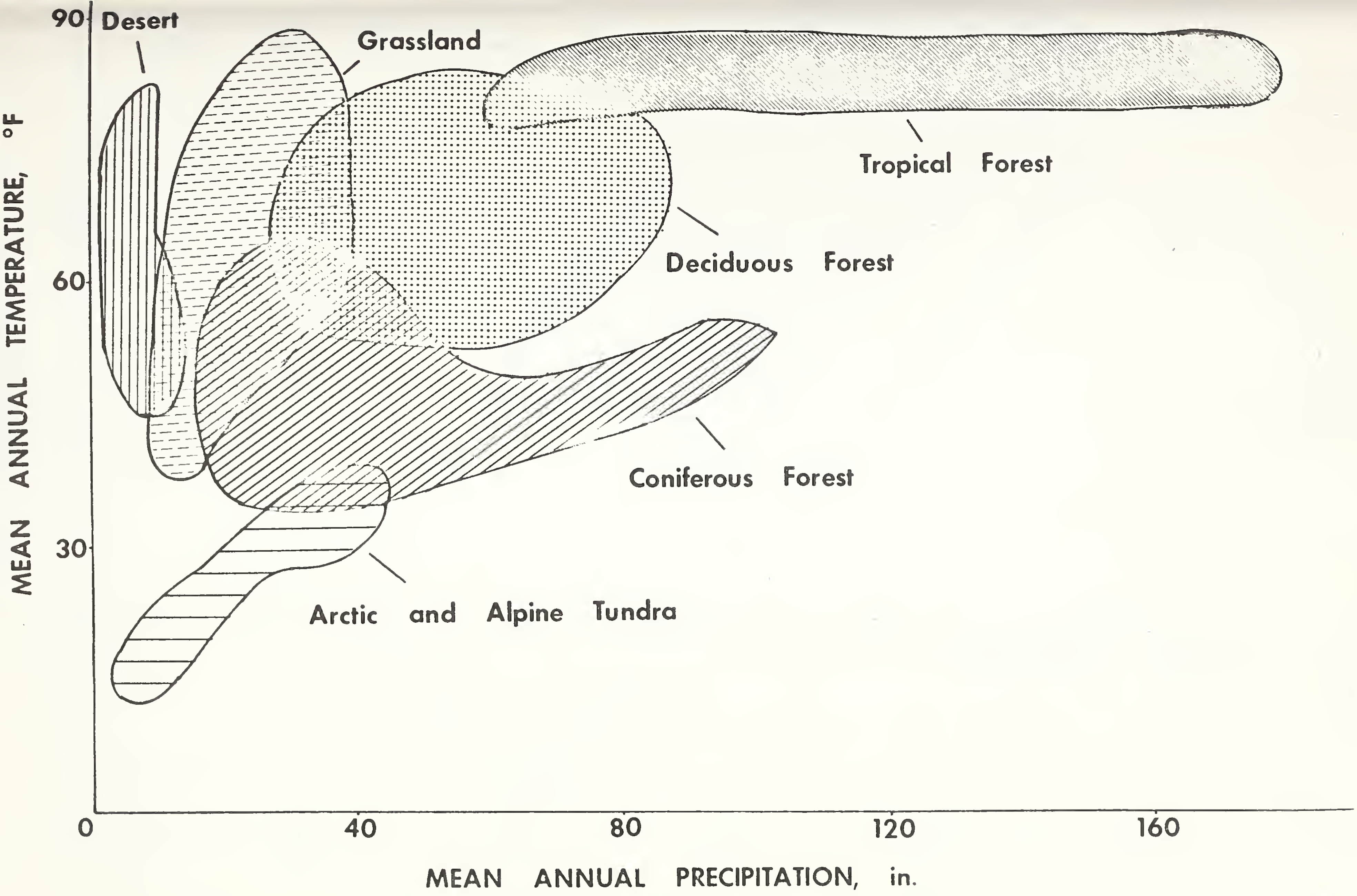
Desert
Grassland
Tropical Forest
Deciduous Forest
Coniferous Forest
Arctic and Alpine Tundra
90
60
30
0
40
80
120
160
MEAN ANNUAL TEMPERATURE, °F
MEAN ANNUAL PRECIPITATION, in.

Fig. 3

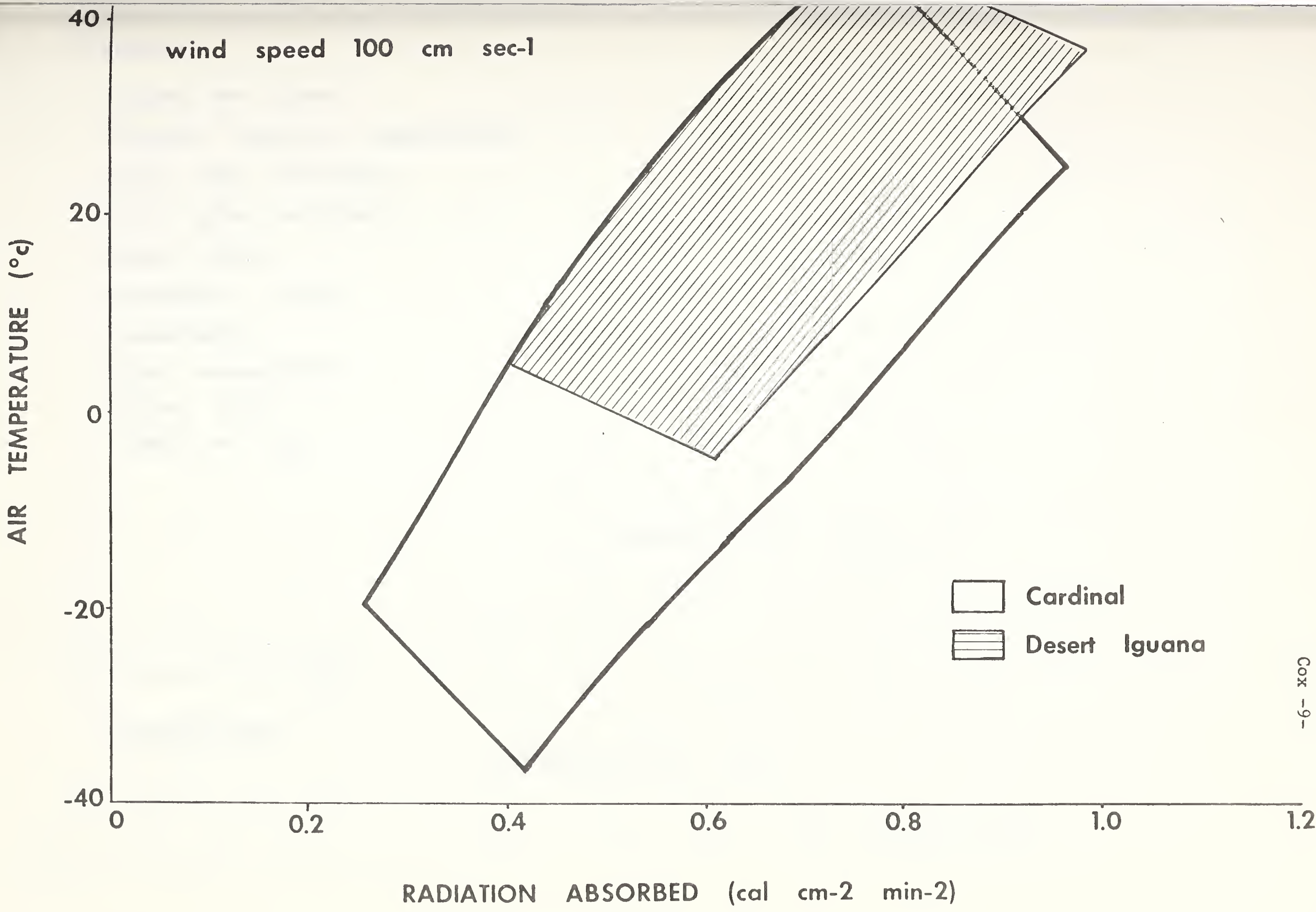
wind speed 100 cm sec-1
AIR TEMPERATURE (°c)
40
20
0
-20
-40
0
0.2
0.4
0.6
0.8
1.0
1.2
RADIATION ABSORBED (cal cm-2 min-2)
Cardinal
Desert Iguana

Fig. 4.

GRASS, GOATS, DUST and DESERTS

Sequence

1.Goats eat grass
2.Higher minimum temperatures
3.Less dew formation
4.Less grass regrowth
5.More dust
6.Radiation cooling
7.Subsidence
8.Less precipitation
9.More dust
(back to six)

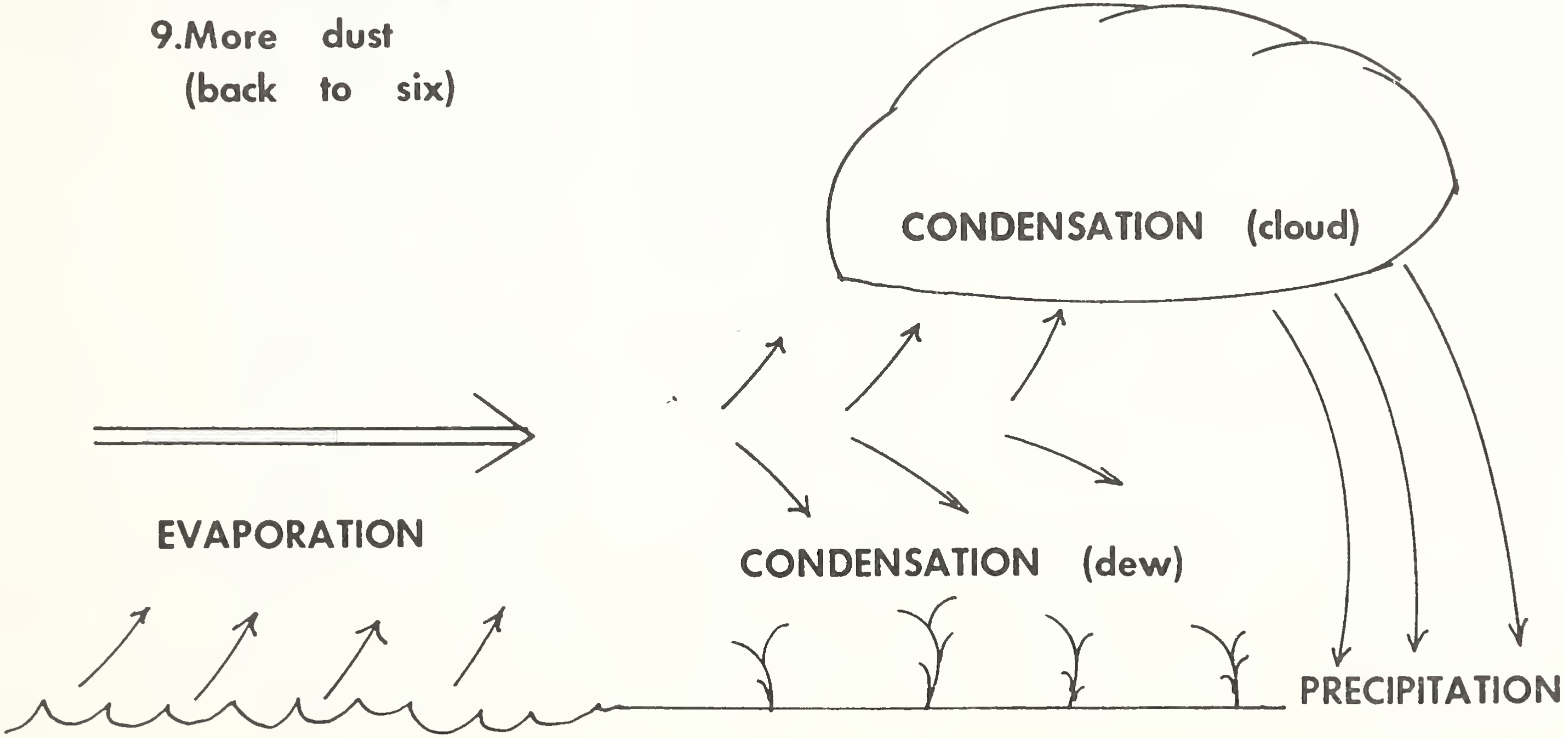

Fig. 5.

PRODUCER FUNCTION

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The major function of green plants in a range ecosystem is that of energy capture in the process of photosynthesis. Carbon dioxide is taken from the air and in the presence of sunlight is fixed into organic constituents within the plant. These organic constituents are then utilized by the plant for maintenance, growth, and reproduction. Radiant energy is therefore transformed into chemical energy within the plant through the photosynthetic process. The fixed chemical energy within the plant is then available for plant function as well as a source of food for consumer organisms. The fixed energy can then flow through the ecosystem in a one-way direction; whereas nutrients cycle through the ecosystem. The photosynthesis process has been referred to as the most important reaction in an ecosystem; and rightly so, for without it life as we know it could not exist on earth.

Before considering producer function in detail, we should briefly review physics and some physical process of energy transformation. Energy may be defined as the capacity to do work. There are five forms of energy. These are: 1. radiant, 2. chemical, 3. heat, 4. mechanical, and 5. nuclear. In producer functioning, we are usually concerned with only the first four forms. Mechanical energy is further subdivided into two types, kinetic or free energy and potential or stored energy. All organisms within an ecosystem require a source of potential energy that can be transformed into kinetic energy and used to drive all life's activities.

Energy to drive the earth's ecosystems is derived from sunlight or radiant energy. From the first law of thermodynamics you will recall that energy may be transformed from one form to another, but is never created or destroyed. Therefore, radiant energy is transformed into chemical energy in the process of photosynthesis. However, the process is not 100% efficient and thus the second law of thermodynamics comes into play. A large portion of the radiant energy reaching the earth is not transformed into chemical energy in the photosynthetic process. Much of the radiant energy is transformed into heat energy which is used to warm the earth and drive the hydrologic cycle.

The sun releases about 2.0 cal/cm^2/min of energy. Much of this energy is reflected or absorbed as it passes through the earth's atmosphere. Atmospheric factors such as water vapor (H_2O), carbon dioxide (CO_2) and ozone (O_3) selectivity absorb some of the solar radiation while minute particles (dust and pollutants) and clouds reflect some of the radiant energy back into space. At the earth's surface we receive about 55 kcal/cm^2/year of radiant energy in the photosynthetically active wavelengths (e.g. visible light). Chlorophyll within the leaf is excited by the blue and red wavelengths of visible light; that is to say that the orbits of sub-atomic particles of chlorophyll are increased. When the orbiting particles return to their natural state, energy is transferred which can then be utilized in fixing carbon dioxide into organic constituents. The wavelengths which are not used in chlorophyll excitation may be reflected,

replenished as plants mature. Grazing animals may drastically reduce reserve storage if plants are defoliated during rapid spring growth or before plants have had an opportunity to replenish reserve stores.

Interactions among abiotic and biotic factors within the ecosystem can cause significant changes in primary productivity. Recent studies have indicated that the interaction between moisture, light, and temperature could limit the rate of photosynthesis of blue grama and western wheatgrass. The maximum rate of photosynthesis decreased with increases in temperature or moisture stress. Nutrients may also be limiting primary productivity of many range ecosystems. Photosynthesis may be directly related to the leaf area; however, canopy structure and leaf orientation also play an important role in determining the rate of organic matter accumulation. If the leaf area is below optimum, then radiant energy is being wasted. Other factors which can significantly effect the efficiency of conversion of radiant energy into bound chemical energy within rangeland ecosystems include: (1) species composition, (2) physiological condition of plants, (3)climatic conditions, (4) age of photosynthetically active tissue, (5) horizontal and vertical distribution of leaf area, (6)seasonal variation in canopy structure and leaf orientation, and (7) optical property of leaves.

Evolution of primary producers in arid and semi-arid rangeland ecosystems is influenced by selection for survival in relation to problems of the physical environment and also by selection involving interactions with and competition among other species of both plants and animals. Natural selection acts at all stages of ecosystem development and appears to act as an efficiency expert. That is to say, selection has been for efficiency of energy transfer among and between trophic levels. Therefore, coevolution has been directed by natural selection and selection has been for genetic characteristics which would allow for the most efficient transfer of energy through the food web.

Prolonged heavy grazing may cause changes in vegetal cover. Vegetation produced is such that it can escape or avoid being grazed by larger herbivores because of low growth habit, low palatability, toxic or noxious chemicals, or season of growth. Many plants from arid and semi-arid rangelands have evolved protective structures to reduce the herbivore-plant interaction. Such morphological structures include thorns, spines, and prickles which may reduce large herbivore consumption of the plant which has such structures. However, these structures may offer protection from predation for small herbivores within the rangeland ecosystem.

Many plants have also evolved storage organs for carbohydrate reserves which are located beyond the reach of large grazing herbivores. Carbohydrate stored within these organs could theoretically be used to replenish growth following removal of photosynthetic material by the grazing animal. Therefore, these storage organs could represent a plant mechanism for enduring pressure of large herbivores.

The location of meristems may also be an important result of the plant-herbivore interaction. Removal of apical meristems by grazing her-

bivores may cause bud activation in lateral dormant buds or in the crown buds resulting in more total growth. This new growth may also be more nutritious for the grazing herbivores. Although the herbage removed may initially be detrimental to the plant, a greater volume of growth or a more photosynthetically active leaf surface caused by bud activation could have a positive net benefit for plant welfare.

We should, therefore, consider the plant-herbivore grazing interactions as possible mutualistic ones for cycling of nutrients and more efficient transfer of energy and nutrients among trophic levels. The fact is that under the apparent handicap of millenia of grazing, most of the dominant species of the world's rangelands are palatable, not only to wildlife, but also to domestic stock. This suggests that the adaptive process in evolution is exceedingly complex and that perhaps we have been unable to discover a dependence of plants on grazing herbivores which is real and important.

In a world that demands ever increasing food production, a primary objective of resource management should be to optimize the energy captured by primary producers. Many of our rangeland ecosystems are today only producing at one-half their potential. Through studies of plant structure, composition, productivity, and vigor as affected by factors of the environment we should be able to determine the factors limiting rangeland production and how we might alleviate the problems. Decisions made by resource managers will play a vital role in determining the amount of energy captured by producers that can subsequently be passed on to other trophic levels within the rangeland ecosystem.

CONSUMER FUNCTION - SECONDARY PRODUCTIVITY

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Secondary productivity is the quantity of organic matter elaborated by organisms during growth and reproduction per unit of time and space. Man is, of course, a secondary producer. However, the thrust of this discussion is directed toward large herbivores which are important, if not essential, links in the food web of man. All animal life is dependent upon primary producers, the primary converters of light energy (solar radiation) into chemical energy usable by man and other animals.

Secondary producers are heterotrophic, holozoic or saprophytic organisms. In contrast, primary producers are autotrophic organisms, either photosynthetic or chemotrophic in nature. While primary producers assimilate energy directly from sunlight and oxidate inorganic materials, secondary producers convert organic material and transfer energy. Furthermore, primary producers are characterized by the uptake of low energy inorganic materials and synthesis and storage of high energy organic matter. Secondary producers are degraders of photosynthate and the transformers of high energy organic matter in plants to flesh and bone in animals.

Important relationships exist between the standing crop of primary producers and the productivity capability of the system. However, this relationship may not be direct because of differences in the turnover rate or the rate of replacement of secondary producers. The rate of secondary productivity may not always be directly related to the standing crop of primary producers because of variations in palatability, nutritive content, and digestibility of the herbage biomass. Greater species diversity of primary and secondary producers usually implies a more stable and resilient community. Furthermore, increased productivity may result when flora and fauna are more complex.

All organisms with the same number of steps or links from the primary producers are considered to be on the same trophic level. In contrast to primary producers, the first trophic level, secondary producers occur on several trophic or feeding levels. Secondary producers vary in kinds and manner of acquisition of foods. Secondary producers also vary in body size, amount, as well as type, of food consumed, digestive systems and metabolic rate. Consumers or primary producers have a wide variety of food species from which to select their diets. Large herbivores have the unique ability to utilize plant materials consisting of carbohydrates, primarily cellulose, because of populations of microflora which inhabit the digestive tracts of all vertebrate herbivores and form a symbiotic relationship with the herbivores. Short chain fatty acids, the end products of microbial degradation of ingested carbohydrates, are primary energy sources for large herbivores. This degradation process is a somewhat inefficient use of energy. However, this symbiotic relationship between herbivores and microorganisms is the important link between the primary producers and the high energy meat products used by man.

The species composition of the diet of large herbivores is of extreme importance in understanding energy flow and nutrient cycling. Certain intrinsic plant qualities, such as sweetness, acidity, nitrogen levels, succulence, etc., result in increased or decreased preference by the grazing animal.These preferences are reflected in the transfers of energy and materials between various trophic levels.

It is well known that in grassland ecosystems frequently the supply of certain macro-and micronutrients may be limited. Certain nutrients are considered critical for maintenance of a high level of secondary production and optimum efficiency of energy flow. These critical nutrients are nitrogen, phosphorus, and carotene. Except in particular cases, other nutrients do not often limit the rate of energy flow. Figures 1, 2, 3, and 4 show the levels of digestible protein, phosphorus, carotene and digestible energy, respectively, in grasses, forbs, and browse at different stages of plant growth. For large, domestic herbivores two levels of requirements are shown. The lactation requirement, however, is similar to growth requirements and gestation requirements are similar to that of maintenance. Complex relationships exist between the rates of nutrient cycling and energy flow to the changing requirements of secondary producers as the levels of nutrient and energy change with the seasons of the year.

In rangeland ecosystems, about 50 percent of the annual net production of plant biomass may pass through the primary consumer pathway. Occasionally large populations of insects, rodents, or small mammals may divert significant proportions of the energy and critical nutrient supply from the large herbivores. The net removal of energy from the ecosystem may approach 10 percent of the primary production. Through fecal and urinary excretions about 50 percent of the biomass and 75 percent of the consumed nitrogen and phosphorus returns to the system. In addition, the heat energy (respiration) used in maintenance is released into the system. Unlike the returned materials, this heat energy is not reusable by other biotic components of the ecosystem. This is a primary example of nutrient cycling and one way energy flow.

Efficiency of secondary production refers to the quantity of animal biomass produced per unit of resources employed. It is important in applying the concept of biological efficiency to natural ecosystems to relate these efficiencies to land resources. Secondary production can be measured in terms of reproduction or increment of growth per segment of time from a given land unit. The relation to the land unit can be based on the amount of fixed energy in primary production.

Biological efficiency can be expressed in numerous ways. For example, secondary productivity can be divided by primary productivity to give an index to trophic level efficiency. Assimilation efficiency is the ratio of food assimilated by a trophic level to the growth or net productivity of that level. This is, perhaps, a meaningful index to the efficiency of secondary producers. Biological efficiencies based on energy flow permit a description of the pattern of activity, and the rate and distribution of energy within an ecosystem. Many different kinds of organisms can be described in the common term of the energy unit.

Energy units are preferable to biomass units to described biological efficiencies since biomass indicates neither activity nor even amounts of living matter. The factors affecting the efficiency of secondary production

are those which influence the available resources used and the products produced.

Biological efficiency when measured as the export of meat for human consumption can be enhanced by the use of fertilizers, manipulation of vegetation, control of pest or competitive animals or by providing proper nutrition by vegetation types or supplements.

The development of energy budgets for a range ecosystem begins with the yield of energy in the forage consumed. The energy costs for the various physiological functions are calculated. The end result is an estimate of the animal response as a measure of rangeland productivity.

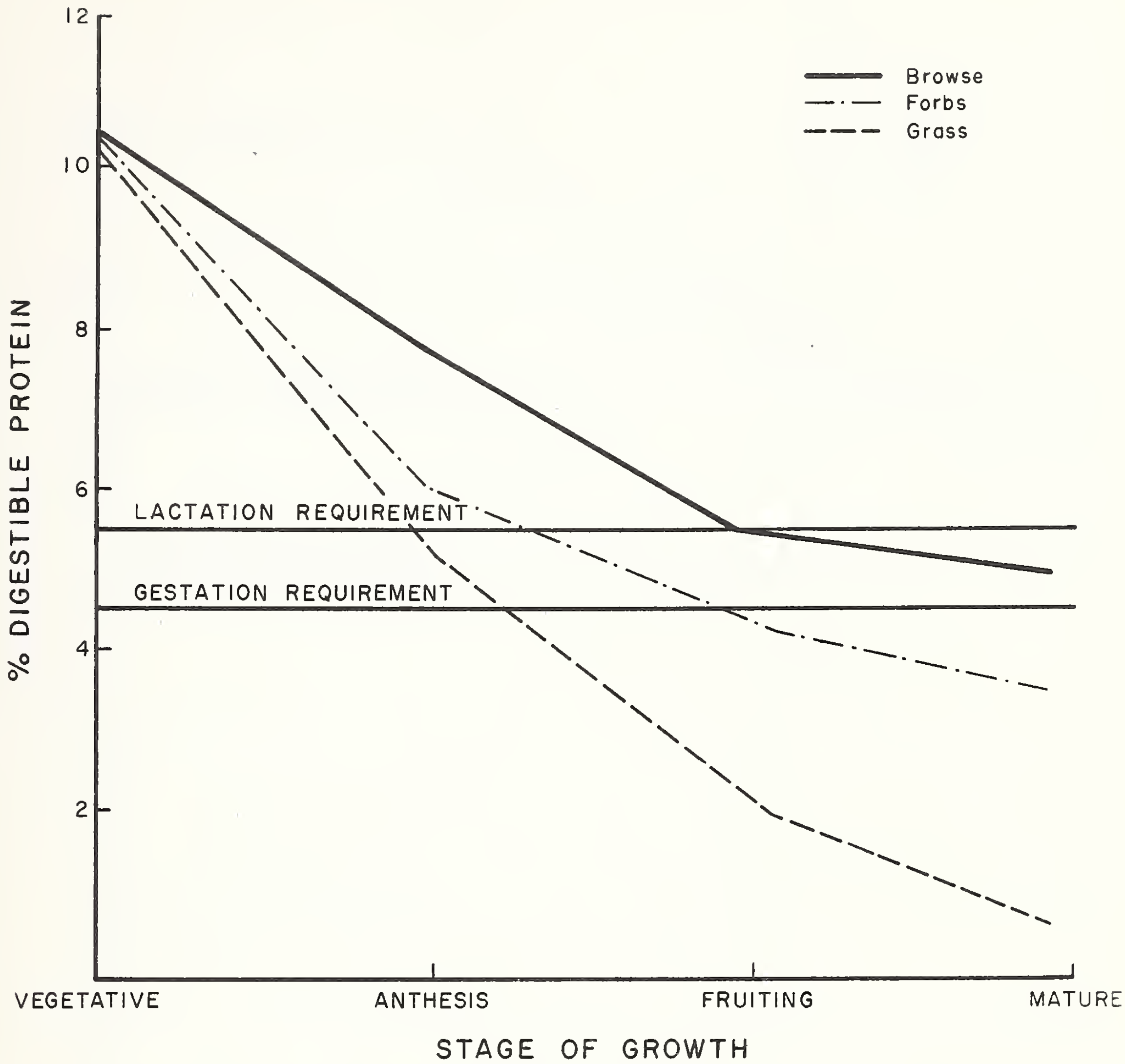

Fig. 1. Percent digestible protein in different forage classes at various stages of plant growth.

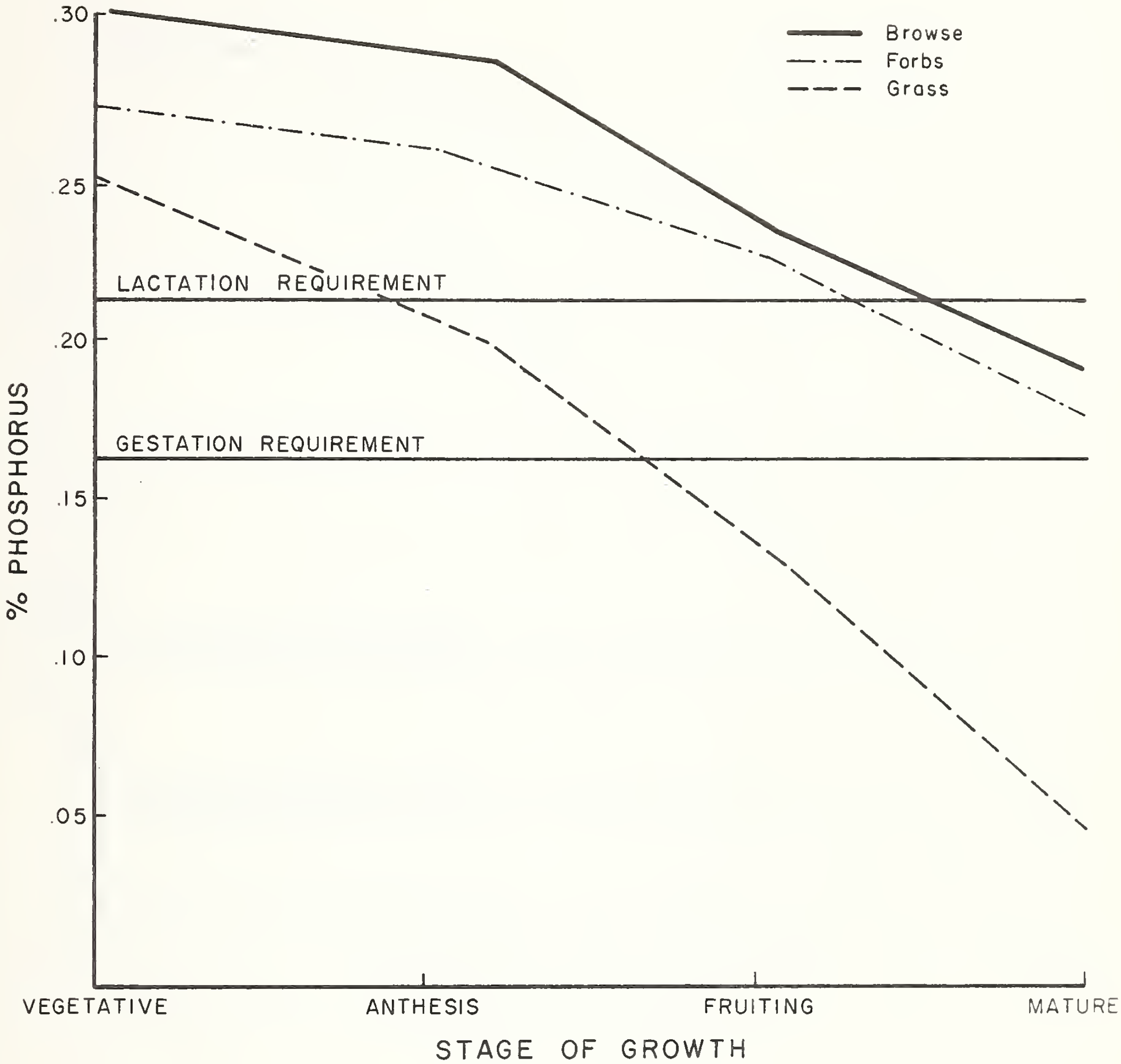

Fig. 2. Percent phosphorus in different forage classes at various stages of plant growth.

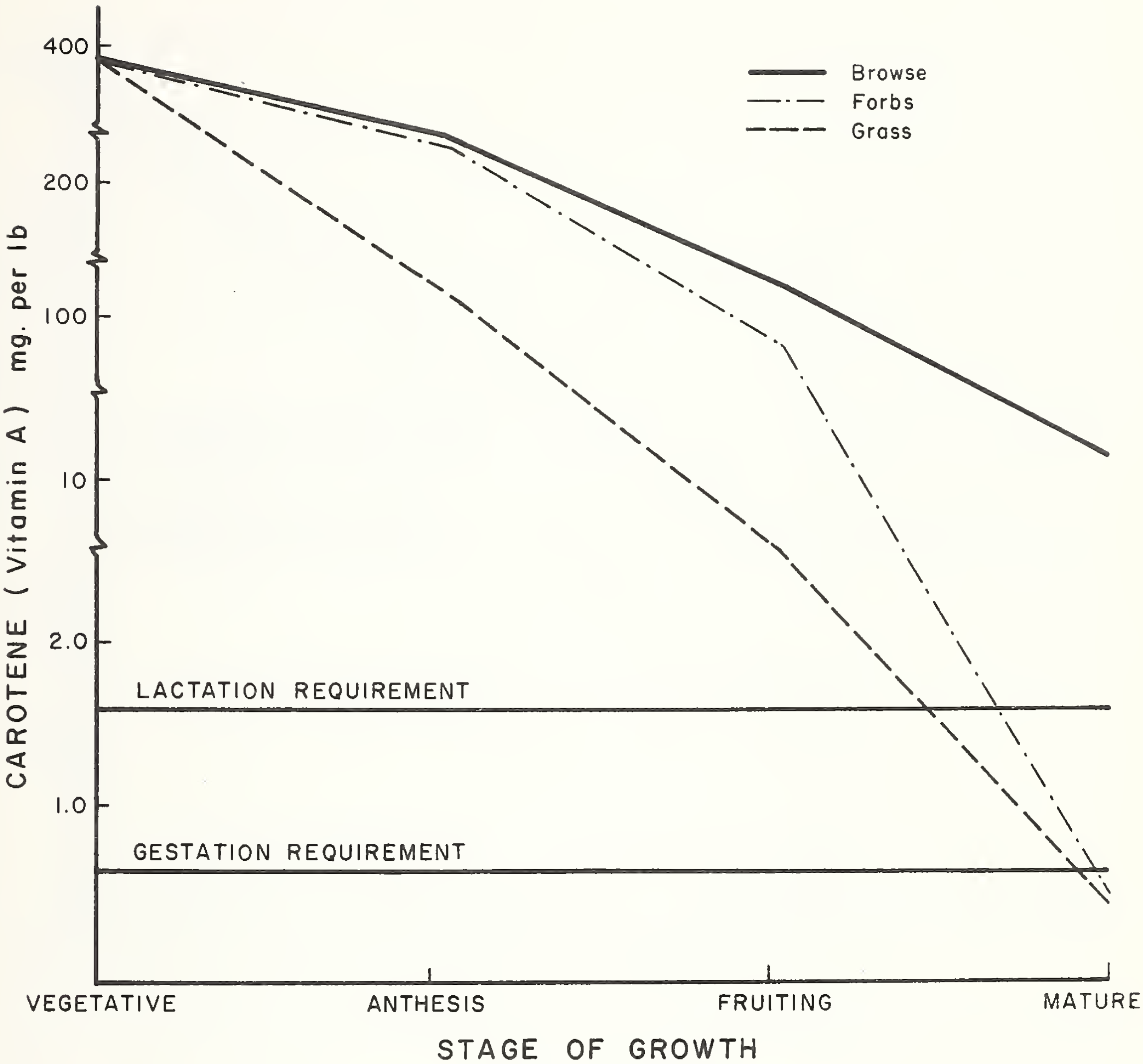

Fig. 3. Concentration of carotene in different forage classes at various stages of plant growth.

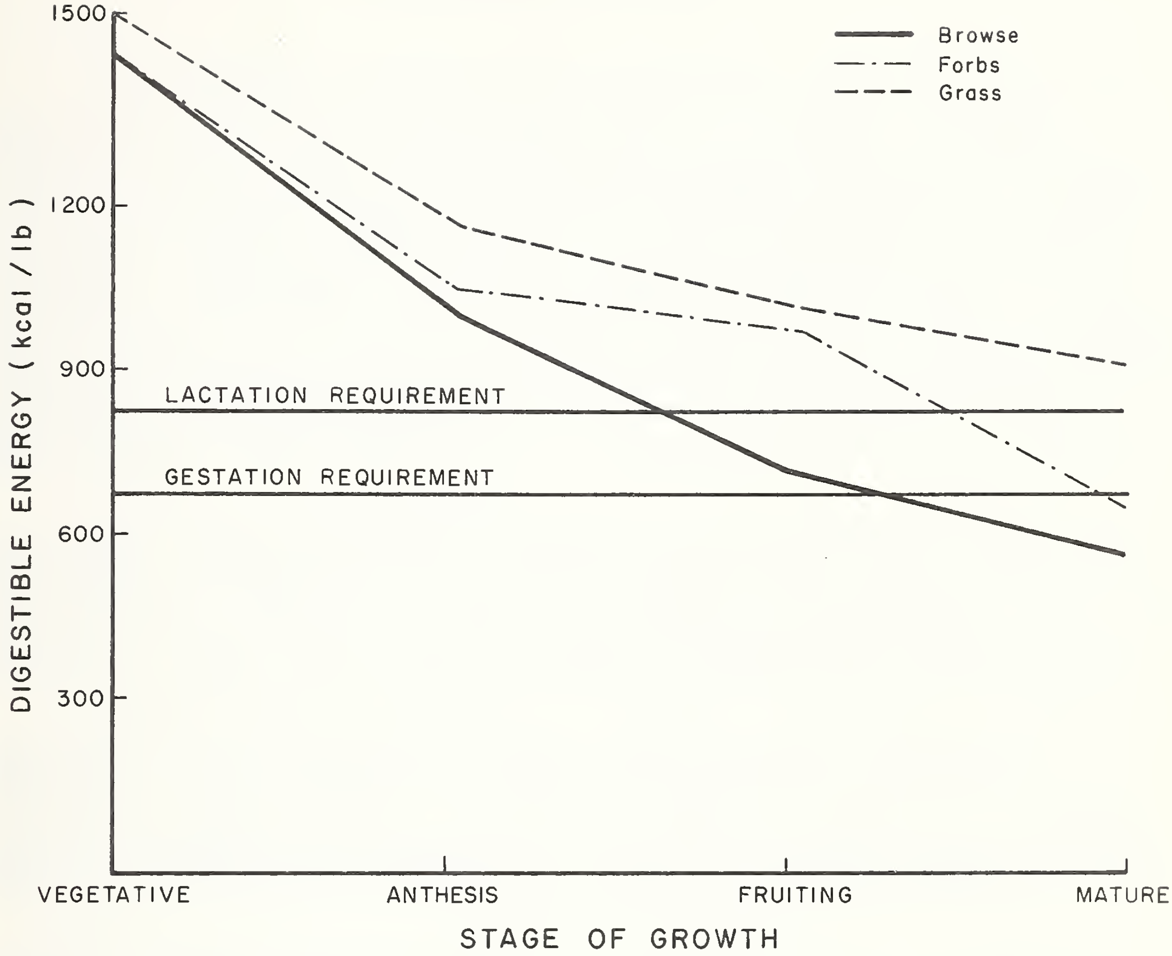

Fig. 4. The amounts of digestible energy in different forage classes at various stages of plant growth.

MANIPULATIONS AND PERTURBED ECOSYSTEMS

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University of Wyoming

The ecosystem is a basic unit for ecological research, and also the basic unit on which the land manager must focus. Understanding the interactions that occur within ecosystems is a major goal of the ecologist. Interactions are perhaps best studied by following the movement of energy and matter from one ecosystem component to another, the components being as follows according to Odum (1971): 1) organic substances 2) inorganic substances 3) climatic regime 4) producers 5) macroconsumers 6) microconsumers. Components 1 to 3 comprise the abiotic phase of the ecosystem, and components 4 to 6 comprise the biotic phase, i.e. the community biomass. Ecosystem components can be classified in other ways also, e.g., herbivores, carnivores, decomposers, etc.; and in actual research a more detailed classification may be necessary, e.g., standing live producers, standing dead producers, mulch, roots, etc.

Ecology can be defined as the study of the structure and function of ecosystems. Ecosystem function implies, among other things, the processes that take place within the system and the manner in which energy, water, and nutrients move through the system. The manipulations exercised during a management program affect both ecosystem function and ecosystem structure.

Ecosystem structure includes the following: 1) trophic structure, essentially the distribution of energy and nutrients 2) ecosystem physiognomy, based mainly on vegetation 3) species structure 4) diversity. A major ecological problem is to relate ecosystem structure to ecosystem function; or in other words, how does ecosystem structure affect ecosystem function? Manipulations usually affect ecosystem structure first.

Trophic structure can be viewed in several ways, e.g., as the proportion of total ecosystem biomass in each of the components, or the proportion of producer biomass in energy transforming tissue and the proportion in support tissue (wood). If the proportions are different in two ecosystems, how is ecosystem function different?

Vegetation physiognomy (or structure) not only serves to synthesize various environmental factors, and thereby serves as a guide to management, but it also modifies ecosystem function. The extent to which vegetation modifies energy, water, and nutrient flux in an ecosystem is determined largely by the structure of the vegetation. Since land management often involves changing vegetation structure, it is important to know how ecosystem function is being indirectly changed. This requires a good understanding of how physiognomy affects ecosystem function.

Species structure refers to the relative abundance of each species by size class or age class. Such phytosociological data are useful for interpreting succession, detecting patterns in nature, and obtaining autecological information.

Species diversity can be defined as simply the number of species per unit area, but more recently the definition has included also the equitability by which each of the species is represented in the ecosystem. Species diversity seems related to ecosystem function, but the relationship is still not clear. The influence of man is often to reduce diversity in order to increase productivity, and this may not always be desirable.

Landscape diversity refers to the number of communities in a landscape unit, e.g., a watershed. Due to human population pressure, a kind of grazing pressure, we are forced to convert more and more land into productive communities, thereby reducing diversity. On the basis of what is now known, land managers should be guided by a policy that supports maintaining as much diversity in the landscape as possible, but land managers will have no choice unless the current rate of population growth in the west, the United States, and the world is curbed. This is the managers biggest problem, and he must contribute toward its solution. It's a social problem. Unless the human population growth rate is curbed, the good management decisions that land managers make today will be of no importance in the long run.

At least some aspects of ecosystem structure and function change after a management practice has been exercised. The system is then said to be perturbed, though a negative connotation is not intended. A great deal can be learned about ecosystems by observing their responses to a perturbation. A major goal of ecosystem modelling is to facilitate the study of perturbation effects by reducing the amount of expensive field work that is otherwise required. If successful, ecosystem modelling can be a tremendous tool for the land manager.

The question often arises, "When is a system overly perturbed?" This question is not easily answered except in extreme cases. Exactly at what concentration of pollutant does a lake become polluted? Again the answer is not clear. The best that a land manager can do is conduct a potential problem analysis of each management unit or district, and then do his best to have the necessary observation made (as funds permit) to decide if the problem actually exists. The completeness and utility of the potential problem analysis will reflect how well the managed ecosystem is understood.

The following outline is a partial list of POTENTIAL problems that could be associated with timber management. The outline serves simply as a checklist for evaluation. Unfortunately, more questions are usually raised than can be answered with confidence. A similar outline could be prepared for park management, grazing, etc.

A. Ecological Problems
   1. Erosion, leading to reduced soil fertility, reduced plant productivity, and stream siltation. A result of managing steep slopes, road buildings or scarification.
   2. Reduced soil fertility due to harvesting. This may not be a problem, but two parameters would have to be known to decide:
      a) The amount of nutrients leaving the area in the harvested wood.

b) The amount of nutrient input via precipitation, wind-blown dust, weathering, and N fixation.

3. Reduced soil fertility due to increased leaching.
   a) More water moves through the soil in some areas because the transpiration pathway has been blocked.
   b) Canopy interception is reduced, but litter interception may increase.
   c) The rate of nutrient leaching and the rate of nutrient input must be known.
4. Altered decomposition patterns which affect plant productivity, a result of modified temperature and litter quality at the soil surface.
5. Altered nitrogen fixation, a result of modifying the forest understory vegetation.
6. Eutrophication, due to either erosion or leaching.
7. Extinction or near-extinction of other plants or animals as a result of management activities.

Note: Management units are often comprised of one or more watersheds. The seven potential problems listed thus far depend in part on the proportion of the management unit that is subject to timber harvest. The following questions are relevant:

a) What proportion of a single watershed should be cut during one season?
b) What proportion of the watershed should be forest over 50 years in age?
c) What proportion should be in forest over 100 years in age?
d) How big should individual clearcuts be?

8. Too much regeneration, resulting in slow tree growth. There is nothing wrong with slow tree growth unless:
   a) the management goal is maximum wood production, or
   b) the short, dense stands of trees are unaesthetic.

   Note: Short, dense stands of trees existed long before man began managing the forest.

   Thinning can solve this problem, but it is expensive. Who should pay for it?

9. Too little regeneration. This is a problem only if there appears to be a need for tree growth or if wood production is the major goal of management. Openings which remain following a clearcut may be used by some wildlife, and, after the slash is gone, they may be aesthetically pleasing if the openings are irregular in shape.
10. Tree growth is too slow. This is a problem only if wood production is the major management objective, or if other resources are threatened in order to get wood which is not being produced rapidly enough to maintain the lumber company.

B. Problems of Value (these problems are always very obvious)
   1. Temporary disruption of other resources.

a) wildlife and not just big game and trout
b) forage for livestock
c) water
d) recreational
e) scientific

Note: Any management practice leads to secondary, unintended ecological changes, but the changes may not be a problem except to those segments of the public with certain values. A segment of the public may tolerate short-term disruptions, but not long-term disruptions. How many weeks, months, or years does a short-term disruption last?

2. Most people need wood, and they see it as a renewable resource. But if they value other resources that may be disrupted by timber harvest, then they may want to have a say in where the wood comes from. Or where it goes after it is harvested.

   The lumber man, however, became established before people placed such value on wilderness, etc. Since he cannot just pick up his sawmill and move, he quite naturally hopes that the people will want him to get their wood from nearby.

   Since most lumber comes from public land, the lumberman often appears to be subsidized. Should he be? From one viewpoint he is performing a service, from another he is degrading the landscape.

In conclusion, every unit of land should be used or managed in the "best" possible way, and a basic understanding of ecosystem structure and function can help determine management decisions. It would seem that management should strive to maintain as much diversity in the landscape as possible, but to do this will require less emphasis on production. Land management must be governed by ecological constraints as well as economic and political constraints. Finally, land managers need to work equally as much on the solution to social problems, such as the population problem, as they do on the technical problems of land management. What may appear to be harmless problems of values may actually lead to serious ecological problems.

DECOMPOSER'S ROLE IN ECOSYSTEM FUNCTION

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INTRODUCTION

Decomposers, or microorganisms, soil insects and soil animals which break down (mineralize) various waste materials from plant and animal growth processes, are essential in continuing ecosystem functioning.

In the pacific northwest, a major management problem results from the inability of decomposers to break down plant litter materials fast enough. With improved fire prevention, the accumulation of plant wastes presents a major management problem. On the other hand, there are environments, such as in intensely cropped areas, where decomposer activities are too easily stimulated by management practices, and a major goal will be to avoid loss of soil organic matter and soil tilth which can result from decomposer activities.

To understand how decomposers control these processes, we should consider the decomposers which are active, their numbers and types, the mechanisms by which they break down litter or detritus materials, and specific management problems particular to various areas of the country.

WHAT ARE THE MAJOR DECOMPOSERS GROUPS?

Bacteria 1-10,000,000/gram soil
Size: 1 x 3 µm (1 µm = 1/25,000 inch)
Forms:  (cocci),  (rods),  (spirilla).

Fungi 10-100,000/gram soil
Size: 3-8 µm diameter, varied lengths
filamentous growth

Actinomycetes 10-100,000/gram soil
same width as bacteria with filaments
actinomycetes give soil its characteristic odor

Other decomposers are soil insects, protozoans and soil animals.

Total decomposer biomass in soils = 4 kg/m^2 (approximately 33,000 lbs/acre)
Most of decomposer biomass is bacteria, fungi and actinomycetes, although soil insects and animals are essential in increasing physical breakdown of materials.

Soil culture plates will be available so you can become familiar with these decomposer groups.

WHAT MATERIALS (DETRITUS) ARE AVAILABLE FOR DECOMPOSITION?

Detritus is dead organic material which has accumulated as a result of primary producer (plant) growth. We also can consider products of algal and photosynthetic bacteria in this category. Of course, the major source of detritus is from the plant photosynthetic activities. Detritus materials represent bound chemical energy derived from sunlight which can be the basis for an entire component of the grassland ecosystem, the detritus feeders.

Detritus feeders are an essential factor in ecosystems management, in that we depend on them to recycle the many waste materials which accumulate in both forest and range environments. In addition, by applying sound management practices, it is possible to either accelerate or delay detritus feeder functions, to achieve particular management goals.

FUNCTION OF DECOMPOSERS

From 75-90% of available detritus is broken down by the decomposers. Without their activities litter would simply accumulate in the ecosystem. Cleary, this does not occur, and we should look in further detail at how detritus feeders function.

a. Return of litter or detritus organic materials to inorganic forms which can be used by the primary producers.

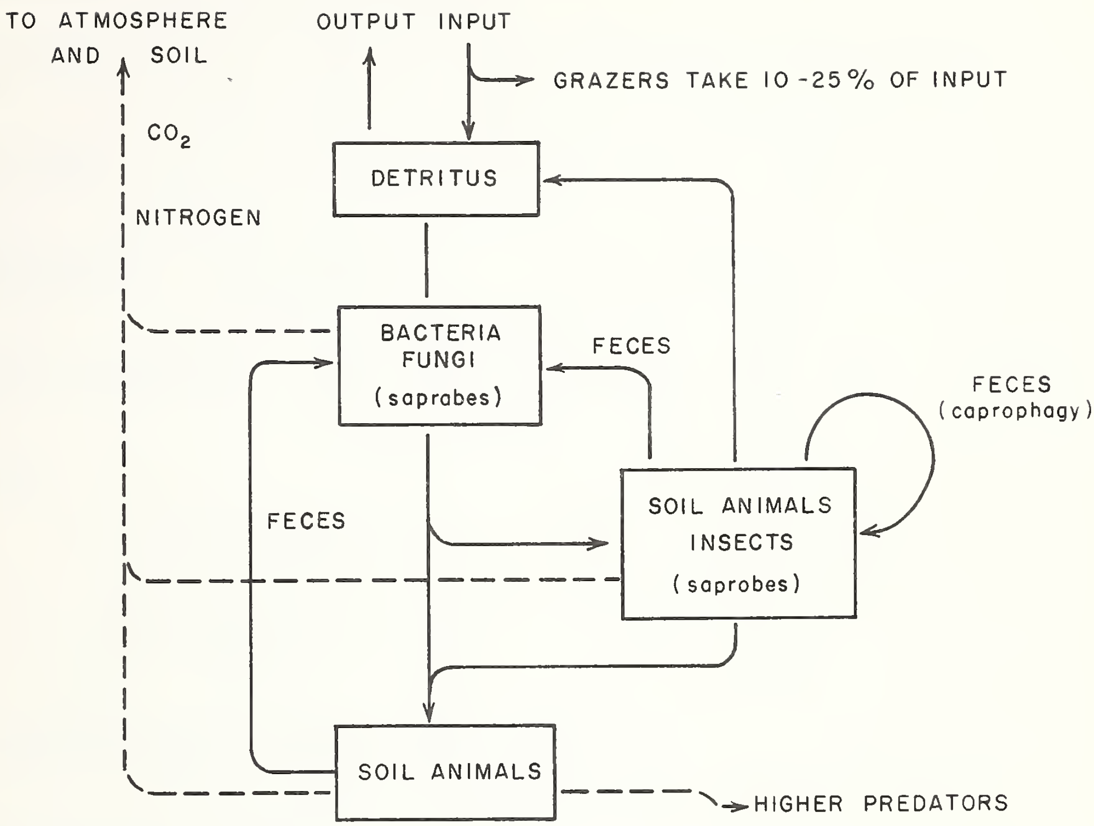
   The transformation of organic carbon to gaseous carbon dioxide which can be fixed by plants together with release of nitrogen, phosphorus and other minerals to the environment is the major function of detritus feeders.

b. Incorporation of detritus components into soils.

   By the breakdown of plant materials the organic content of soils can be increased. This improves soil structure, ability to retain moisture, and the suitability of a soil as a medium for plant growth.

c. Provision of a food net for predators which live by capturing detritus feeders.

   Many birds and mammals survive by predation of soil detritus-dependent insects and animals. This is a major base upon which higher predator pyramids are built.



ENERGY FLOW IN THE DECOMPOSER FOOD WEB

Figure 1 shows the flow of energy and nutrients in the decomposer food web. First utilization is by the saprobes, or consumers of dead plant materials. Other predators can then use the saprobes as a food source. At each point in decomposition complex organic materials are transformed to their basic "building blocks" which can be used again by the primary producers.

Detritus materials can also be removed by the grazers, or organisms such as herbivores and insects which depend on standing plant material for their existence. Most studies have indicated that for a grassland environment, only 5-10% of vegetation goes through grazers, and this percentage may rise to perhaps 25% on intensively managed cattle-feeding areas. We should also note that much of this grazed matter returns to the soil in the form of fecal material.

DECOMPOSER TERMINOLOGY

Mineralization - the transformation of organic compounds to inorganic breakdown products.

Immobilization - the incorporation of plant nutrients into microbial cells, making this temporarily unavailable to plants

Nitrification - the microbiological transformation of ammonia nitrogen to nitrites and nitrates

Denitrification - the transformation of nitrate and nitrite nitrogen to nitrogen gas by microbiological processes

Nitrogen volatilization - the loss of fertilizer nitrogen to the atmosphere by chemical and biological processes

C/N ratio - the ratio of carbon to nitrogen in a plant material

C/N ratio in a plant = less than 20-1 = mineralization of nitrogen can occur

C/N ratio in a plant = more than 30-1 = immobilization of nitrogen can occur

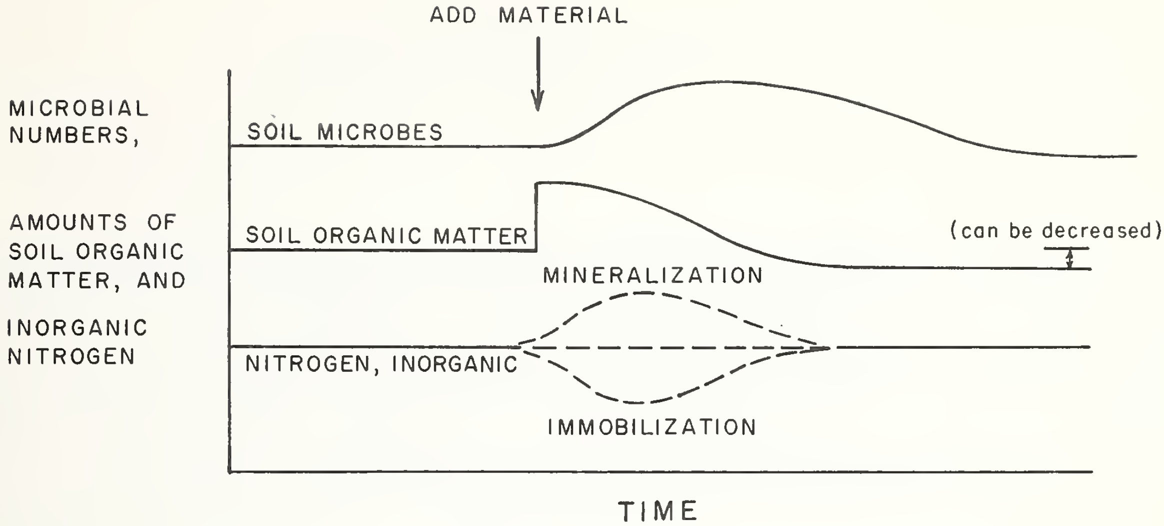
With increasing plant age, the amount of nitrogen decreases, giving a higher C/N ratio, and a greater chance for immobilization to occur when this older material decomposes.

Nitrogen fixation - symbiotic - the process of nitrogen fixation carried out by legumes

Nitrogen fixation - nonsymbiotic - the process of nitrogen fixation carried out by bacteria (primarily *Azotobacter*) and algae in the soil.

WHAT TYPES OF SUBSTRATES ARE AVAILABLE FOR USE BY THE DECOMPOSERS?

	Decomposition is		
	easy	moderate	difficult
Carbohydrates	X		
Amino acids	X		
Starch		X	
Cellulose & hemicellulose		X	
Proteins		X	
Lignins			X
Chitin (from insects)			X



WHAT CAN HAPPEN IN SOIL WHEN MATERIALS ARE DECOMPOSED?

In Figure 2, the addition of a waste material can cause an increase in microbial populations and activities; depending on the C/N ratio, mineralization or immobilization can occur. After decomposition of the added material, the activated microbes may actually decompose native soil organic matter, leaving the soil in poorer condition than before the waste was added!

WHAT MANAGEMENT ALTERNATIVES DO WE HAVE FOR CONTROL OF DECOMPOSER ACTIVITIES?

Amount of materials added, and season
Locations of materials - surface, subsurface
Grinding of materials
Temperature
Moisture level (aeration) by irrigation or drainage
Addition of trace nutrients such as nitrogen
Burning to accelerate removal
Plowing and disturbance of soils
Removal from particular areas to eliminate excessive accumulation

LITTER MATERIAL BREAKDOWN AND ACCUMULATION EFFECTS ON ECOSYSTEM FUNCTION.

a. Influence on rain water absorption - water retention properties.
b. Influence on soil temperature.
c. Possible toxicity of detritus breakdown products.
d. Influences on seed germination, both favorable and unfavorable.
e. Allowance of more diverse insect, animal, and small predator populations in the ecosystem.

SOILS FACTORS AND NUTRIENT CYCLING IN ECOSYSTEM MANAGEMENT

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Colorado State University

I. Introduction

Modern concepts of the effect of soil factors on the ecosystem require an understanding of basic soil concepts and soil-plant relationships. Nutrient cycling rates depend on chemical and biological processes within the soil system. Plant growth rates are often controlled by nutrient availability. Thus the processes controlling nutrient availability are often a rate limiting step in total ecosystem productivity. The basic principles are also valuable in evaluating potential losses of nutrients from the soil to ground and surface waters. Such losses are important, both in terms of the loss to the soil system and the undesirable enrichment of lakes and streams. Nitrogen phosphorus and potassium are of principal interest, but many of the principles are applicable to other elements.

In this lecture we will review some fundamental concepts of soil science and discuss the implication of these concepts with respect to the cycling of nitrogen, phosphorus and potassium in the ecosystem.

II. Soil Properties and Processes

A. Surface Area and Exchangeable Cations

Many properties of soils arise from the activity of the particle surfaces, and surface areas may be very large. Typical surface areas would be of the order of several acres per pound of soil. These surfaces carry a preponderance of negative electrostatic charges. These negative charges are balanced by a "swarm" of cations (positively charged) in the solution surrounding the soil particles. These cations provide an important reservoir of desirable plant nutrients such as calcium, magnesium and potassium. Unfortunately they may also serve as a reservoir of undesirable cations, particularly sodium and aluminum. Excessive concentration of these cations adversely affect soil properties. (See II-B and II-C below)

B. Soil Acidity

While most people concerned with soil management are familiar with the pH scale, the logarithmic nature of the scale is often forgotten. We must remember that the H^+ and OH^- concentrates each change 10^- fold for every pH unit. In acid soils we find that the free acidity (active H^+ ions in solution) accounts for only a very small fraction of the total acidity of the system, i.e. the soils are highly "buffered". In older concepts this buffering capacity was assumed to arise from the release of H^+ ions adsorbed on the negatively charged clays. At present this concept is considered inadequate as most reserve acidity seems to arise from the presence of Al^{+++} ions and charged Al-OH complexes that are adsorbed in the clay systems. A simplified but reasonably valid model of this effect can be constructed by the reaction of an acid (H^+ ions) on $Al(OH)_3$ (gibbsite).

$$Al(OH)_3 + H^+ \rightarrow Al(OH)_2^+ + H_2O$$

$$Al(OH)_2^+ + H^+ \rightarrow Al(OH)^{++} + H_2O$$

$$Al(OH)^{++} + H^+ \rightarrow Al^{+++} + H_2O$$

The Al(OH) complexes or the Al^{+++} ions are then adsorbed on the negative charges on the clay surfaces. If a base is added these Al ions and complexes act as an acid.

$$Al^{+++} + 3OH \rightarrow Al(OH)_3$$

Thus soils with a large portion of their negative charges saturated with Al may be very acid. In many cases deleterious effects on plant growth may be the effect of Al toxicity rather than of acidity per se.

C. Salinity

In arid areas we often find soil affected by undesirable concentrations of soluble salts. Such salinity problems are often erroneously blamed on excessively high pH levels or "alkalinity". Some salt affected soils are indeed very alkaline, but others may be neutral or in some cases even acidic. These problems usually arise as a result of inadequate drainage.

As groundwater moves through soils and rocks it picks up soluble salts. If this water accumulates in poorly drained areas it moves to the surface by capillary action. As the water evaporates from the surface the salts are left behind resulting in salt accumulation. If the salts are high in sodium poor physical condition may result. Management of salt affected soils usually requires improved drainage and use of salt tolerant plant species.

D. Intensity-Capacity Concepts

1. Nutrients Held As Exchangeable Cations

A very useful concept in understanding the ability of soils to supply nutrients for plant growth involves the intensity-capacity principle. The major supply of available nutrient cations is held on the cation exchange complex rather than being freely distributed in the soil solution. Important cations held in this manner include Ca^{++}, Mg^{++}, K^+, and NH_4^+. As these cations are removed from the solution by plant uptake, they are replaced by ions from the exchangeable pool. Sufficiency of supply thus requires both that the equilibrium solution concentration at any time be high enough to meet plant requirements (intensity), and that the exchangeable supply be large enough so that it will not be depleted by plant uptake (capacity).

2. Nutrients Controlled by Solubility

With other ions the solution concentration is governed by solubility relationships. The available pool is composed of slightly soluble compounds that are in equilibrium with the concentration of the nutrient in solution. The solution concentration at any one time is very low, but as the nutrient is removed from solution by plant uptake it is rapidly replaced by ions dissolving from this labile (available) pool. Here again, sufficiency for plant needs involves both the amount in the labile pool (capacity), and equilibrium solution concentration (intensity). If the solution concentration is too low the plant will be unable to take up enough to meet its needs. If the labile pool is too small it may become depleted, causing a lowering of the solution concentration. Nutrients governed by this type of availability system include Phosphorus, Boron, Zinc, Iron, Copper, and Manganese. The Zn^{++}, Fe^{++}, Cu^{++} and Mn^{++} ions may also be held on the exchange complex but under conditions where supply is likely to limit crop growth they are apparently largely controlled by solubility relationships.

3. Highly Soluble Ions

A few nutrient ions are highly soluble and whenever the soil is moist exist largely in solution. Nitrate and chloride fall in these categories. Such ions are highly susceptible to leaching, being free to move with the soil water. Sulfate ions for the most part also belong to this class although at high concentration precipitation will occur.

III. Nutrient Cycling

A. General Consideration

The current clear cutting controversy has recently focused a great deal of attention on nutrient cycling and availability as a rate limiting step in forest ecosystem productivity. The emotional and pseudo-scientific nature of much of the written material is reminiscent of the soil erosion literature of the 1930's. Controversies of this nature exist as a result of a lack of understanding of the system. Forestry research in the past has largely neglected nutrient cycling, a situation made clear by the present controversy. While a tremendous body of knowledge of soil-plant nutrient relationship is available from 100 years of research on agricultural ecosystems, there is a serious gap in our knowledge of its applications to the forest systems.

B. The Soil Phosphorus System

As noted above the intensity-capacity relationships of soil phosphorus are controlled by the solubility equilibrium. The characteristics of this system are such that, with the exception of a few coarse and unreactive soils, only a very small portion of the "available" P in the system is in solution at any one time. The solution concentrations are low, generally on the order of a few tenths of a part per million. When rapidly growing plants are removing solution P, the daily removal may exceed the amount in solution. In other words the "turnover" rate of solution P may be greater than 1 per day. The solution P is replaced by dissolution of labile P and by mineralization of P in soil organic matter, litter and roots.

If plant removal is less than mineralization the excess is precipitated as "labile" phosphorus (See Fig. 1). If the rate of mineralization of organic P is less than the rate of plant uptake, the labile pool is depleted. Very little P is added to or removed from the system. Weathering of mineral P is generally slow. This rate depends on the amount and form of the P minerals and the chemical and biological properties of the soil. Where very high levels of labile P are present some may be precipitated as insoluble P minerals.

Applied phosphorus fertilizers do not remain in solution but are converted to slightly soluble compounds that become part of the labile pool "available P". As a direct consequence of the low equilibrium concentration of solution P, leaching of either native or applied P through the profile and into ground and drainage waters is generally negligible. If soil P enters lakes and streams it is generally the result of surface runoff and erosion carrying materials high in P directly into the stream. Perhaps the most important factor in preventing soil P from entering waters is erosion control. Where surface erosion is a hazard it would seem advisable to incorporate fertilizer P into the soil to prevent physical transport by surface waters.

C. Nitrogen Cycling

Nitrogen availability undoubtedly limits productivity in more ecosystems than any other mineral nutrient. This system differs from the phosphorus cycle in several important aspects. The processes controlling flow are more biologically controlled and less dependent on chemical equilibrium than in the P systems. However, in both systems only a small portion of the total amount involved in the biological system is available for plant uptake at any one time. Nitrogen flow in a grassland system is shown in Fig. 2.

The vast majority of soil nitrogen is tied up in organic compounds and only subject to movement by physical transport. The relatively small portion available to plants at any one time will be either in the nitrate or ammonium forms. The ammonium form is positively charged and quite firmly held due to its attachment to the negatively charged clays. The ammonium may be biologically converted to nitrate, which is extremely mobile. If nitrate is present when water passes through the profile, the nitrate will be carried with the water. Thus, nitrate forms may easily be leached into ground waters. Prudent management practices, thus, dictate that high nitrate concentrations be avoided at times when water is likely to pass through the profile.

Relatively large amounts of N may be lost through harvest, or in forests by burning. If no plants are growing and actively taking up the nitrate and ammonium forms these may build up in the system and be lost through leaching. If large amounts of low carbon plant residues such as straw or wood are present this N may be tied up by the microbes

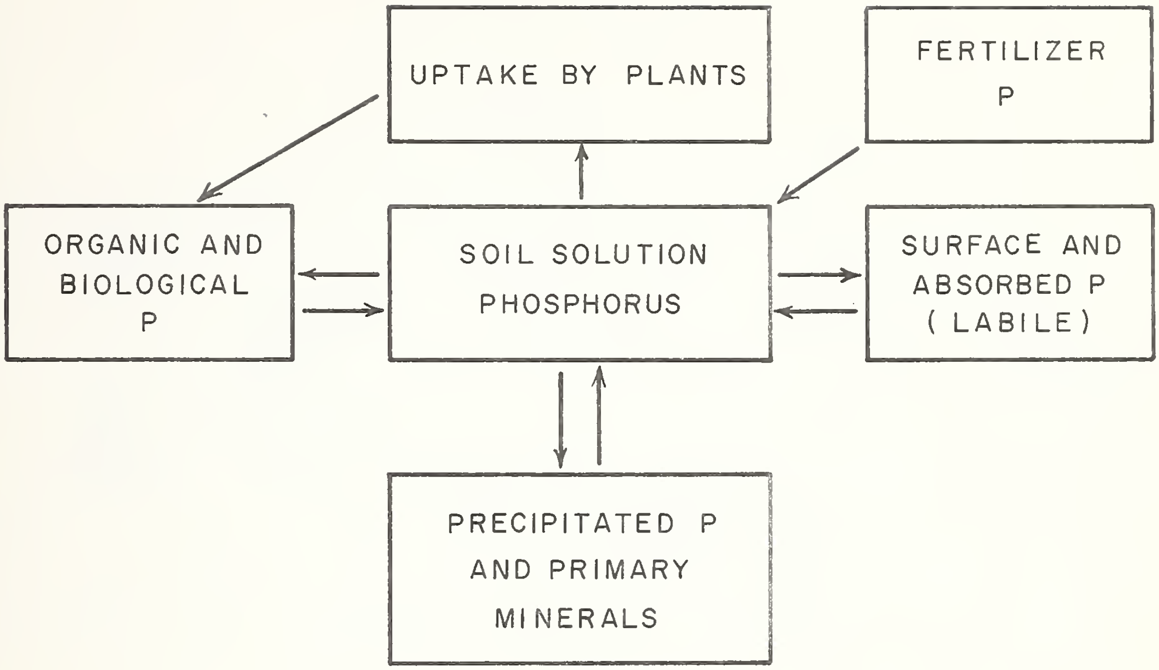

Figure 1. Compartmental diagram of SOIL phosphorus equilibria.

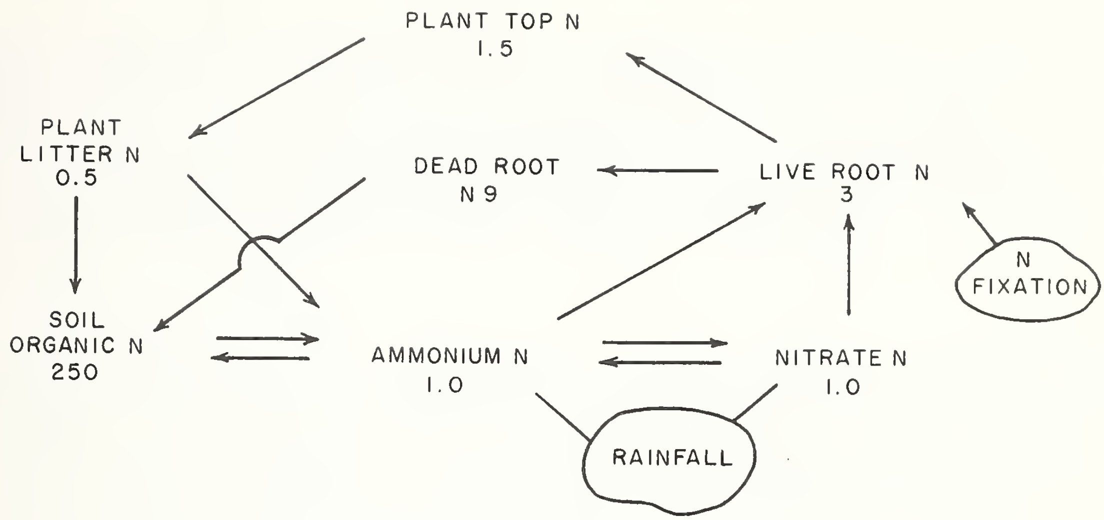

Figure 2. Simplified soil nitrogen systems. Numbers show grams N/m^2 for a typical grassland ecosystem.

ECOSYSTEM DATA COLLECTION, AVAILABILITY, AND PROCESSING

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Data collection has always been an important function of natural resource management and the extension of management concepts to include all components of an ecosystem has increased the need for data collection. This does not necessarily imply that more data needs to be collected but rather different kinds of data are necessary for decision-making with regard to the total system. A close examination of the data needed and its subsequent collection needs to be made for each set of decision alternatives. It may be that automated data collection techniques will be useful as data requirements increase. Data acquisition techniques are numerous and selection depends on the kind of data needed. The automated techniques have not been extensively used for ecosystem management purposes.

There are basically three characteristics of data for management decision-making that need to be considered. These include: data collection or acquisition, data availability, and data processing.

Data can be acquired in a number of ways. The method of data acquisition depends largely on the data use requirements. Data acquisition techniques fall into one of three categories: 1) field forms; 2) port-a-punch cards; 3) electronic methods.

General field forms and their use are well known by the experienced management specialists. That is, for several decades natural resource managers have collected field data on individually custom-designed forms to meet their particular needs. These forms were usually designed with field convenience in mind rather than any subsequent automated data processing. The data can usually be keypunched directly from these forms, but usually must be transferred to forms specifically used for keypunching. The turn around time for data processing using this type of data form is usually rather lengthy. These forms are convenient, flexible, and can be designed to meet the technician's requirements. However, the disadvantage of using individually designed data forms lies in the fact that subsequent data transfers must be made before further processing is accomplished. This is true only if computer systems are used for the data processing.

Other field forms that are available and becoming widely used are designed to be processed by automated techniques. These techniques include the use of an optical scanning device and vary in their design. Figure 1 is an illustration of such a form which can be used on an IBM 1231 optical reader. These forms can be conveniently arranged by using an over-printing technique to obtain the necessary data. One such arrangement is illustrated in Figure 2. This particular type of data form can hold 1,000 bits of information.

Port-a-punch cards have only 40 columns for data recording. There are probably more disadvantages in using this type of data collection technique than exists in the other two methods. These disadvantages include errors in punching, physical limitations on use of the cards and the cards are much heavier than the other forms.

Figure 1.

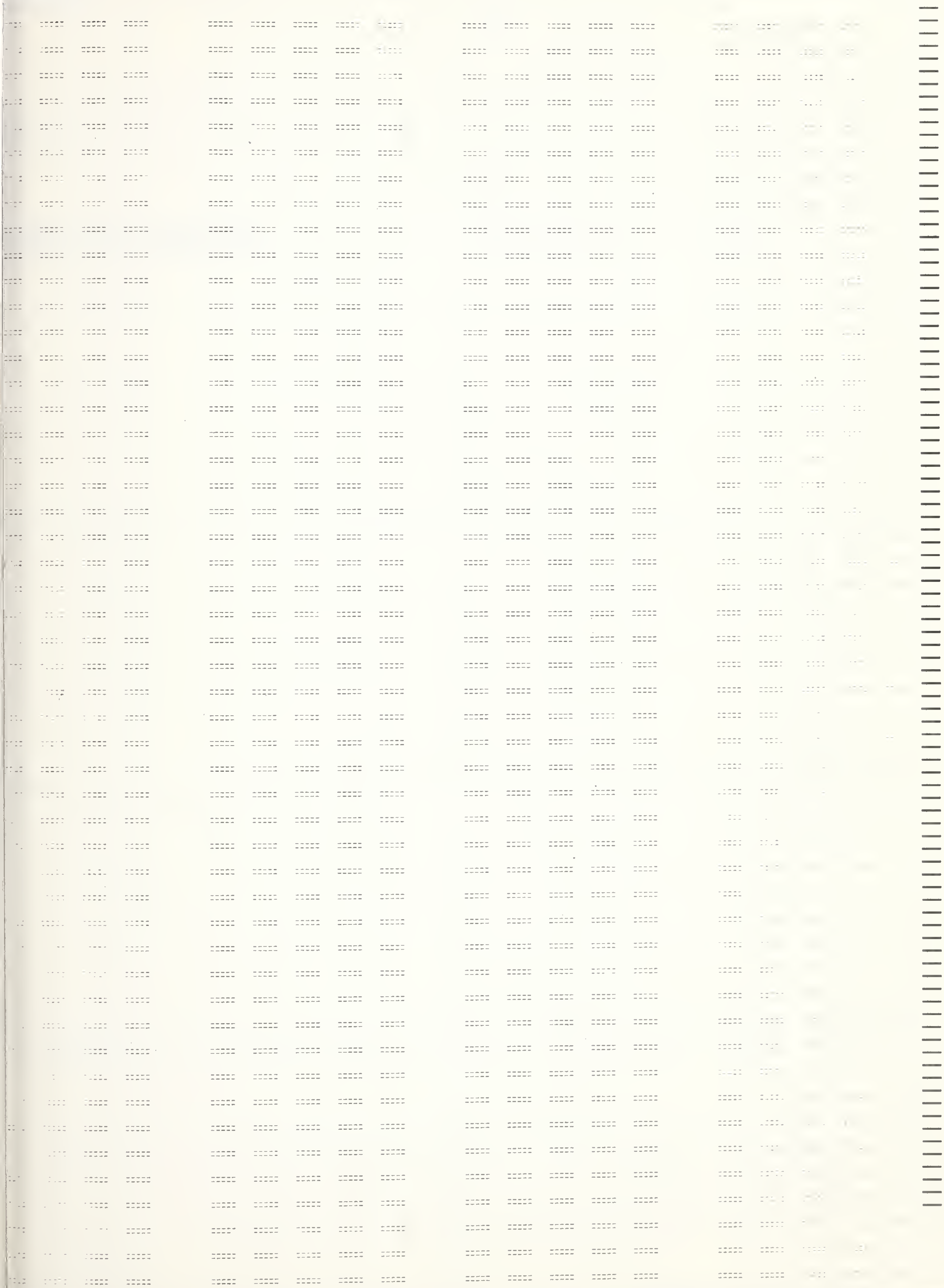

Figure 2.

MAL NUMBER

1	2	3	4	5	6	A	B	C
1	2	3	4	5	6	7	8	9
1	2	3	4	5	6	7	8	9
1	2	3	4	5	6	7	8	9

ERVER

1	2	3	4	5	6	7	8	9
1	2	3	4	5	6	7	8	9
1	2	3	4	5	6	7	8	9

DATE

MONTH:		Jan	Feb	Mar		Apr	May	Jun		
		Jul	Aug	Sep		Oct	Nov	Dec		
DAY:	0	1	2	3						
	0	1	2	3	4	5	6	7	8	9
YEAR:		65	66	67		68	69	70	71	72

COMMENTS ON BACK YES

R NUMERIC DATA IN DEFINED AREAS

1	2	3	4	5	6	7	8	9	**41**	0	1	2	3	4	5	6	7	8	9
1	2	3	4	5	6	7	8	9	**42**	0	1	2	3	4	5	6	7	8	9
1	2	3	4	5	6	7	8	9	**43**	0	1	2	3	4	5	6	7	8	9
1	2	3	4	5	6	7	8	9	**44**	0	1	2	3	4	5	6	7	8	9
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1	2	3	4	5	6	7	8	9	**47**	0	1	2	3	4	5	6	7	8	9
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1	2	3	4	5	6	7	8	9	**79**	0	1	2	3	4	5	6	7	8	9
1	2	3	4	5	6	7	8	9	**80**	0	1	2	3	4	5	6	7	8	9

The electronic methods for data acquisition include two major types. The standard tape recorder has been used in collection of field data. The magnetic tape is submitted directly to a keypuncher for transcriptions. The portable digital recorder is the most widely used of the electronic methods. One particular example is shown in Figure 3. Magnetic tapes are used with this type of system and is converted to a computer compatible format automatically.

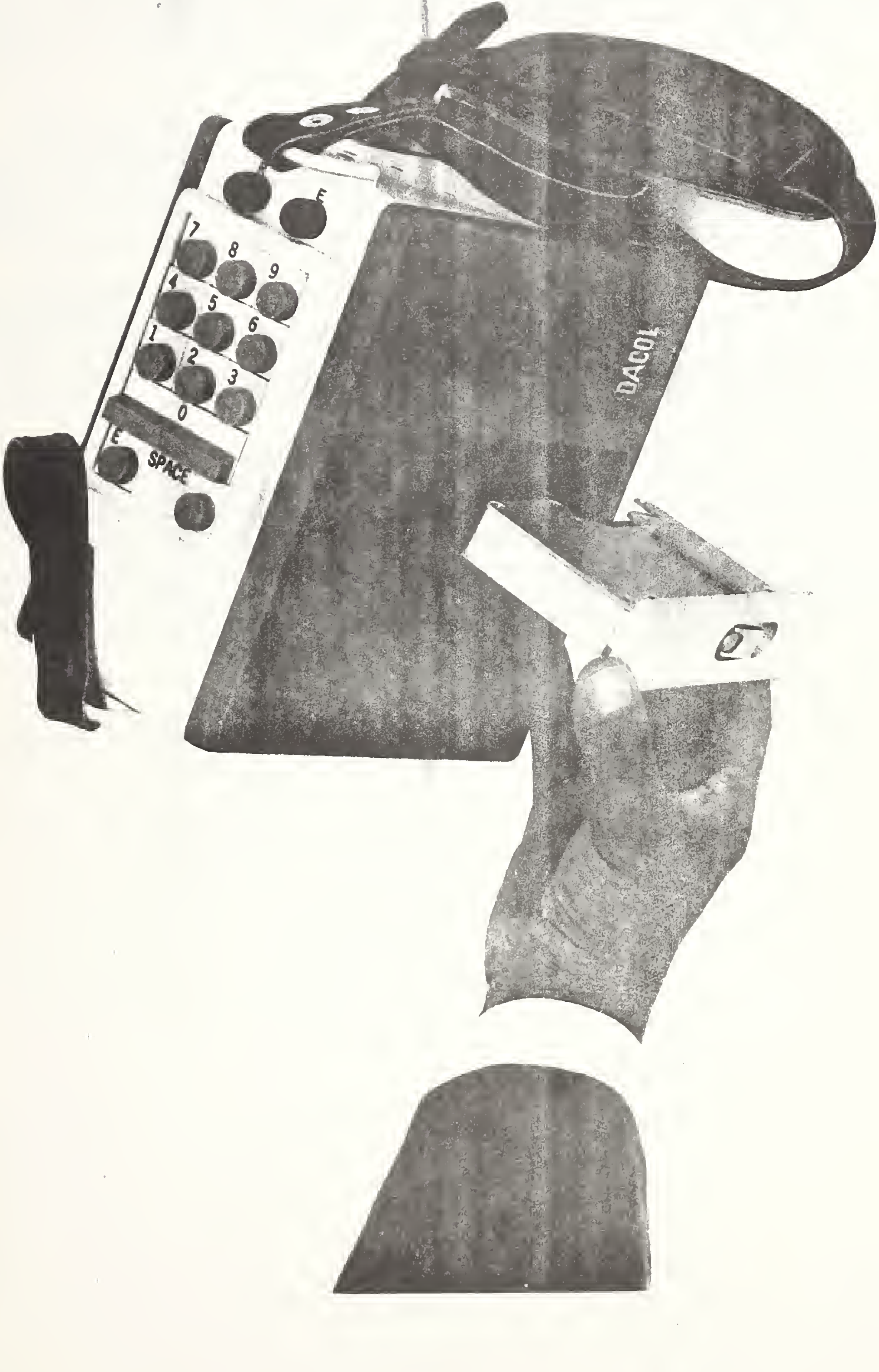
Any data acquisition technique ought to include advantages as follows: 1) increase the accuracy of the final results; 2) lower the time for acquiring and processing field data; 3) reduce human error; 4) be easily handled in the field; and 5) be in a format for easy storage and later reference.

The availability of data for use in decision making in range ecosystems decision making presents immediate problems. Normally, an abundance of data exists for ecological descriptions of each ecosystem under management. That is to say, the land manager has readily available most of the ecological characteristics of the area under his supervision. However, a number of these characteristics are not readily available for use in decision making. The most important ecological variables for decision making include: precipitation, temperature, soil characteristics, and herbage production. Herbage production is often required to be in the form of mean production by seasons. Furthermore, some estimate of variability by seasons and years is also required for decision making. Most of the data available concerning herbage production is with respect to end of season standing crop. There are techniques for obtaining appropriate information for standing crop by seasons when only end-of-season information is available. These are presented in detail in the lecture. Soil characteristics are available after the usual soil mapping procedures have been completed by the SCS or an appropriate agency. Most of the information for decision making with respect to soils can be used directly or can be easily obtained from the available information.

Data other than biological, have to be obtained from agencies who are primarily concerned with sociological and economic characteristics of the ecosystem. These data are normally available from the Census Bureau, HEW, Statistical Reporting Service, and Federal banking institutions, etc. This type of data is available on computer systems and is such that it can be easily used for decision making. It is apparent that cooperation is needed from each of the agencies that have the respective data in order to obtain the appropriate data for the total management of the ecosystem.

Data processing for management decision making with regard to ecosystems requires up-to-date techniques. These techniques include the use of large computers because of the amount of information necessary for decision making. Furthermore, computers can do even simple calculations much faster than can the human mind.

Data processing includes the use of computer storage-retrieval systems. Storage retrieval systems are highly developed software systems which are available for computer user requirements. Generally such systems



DACOL DIVISION -- Model R41 Portable Keyboard Digital Magnetic Tape Recorder

Figure 3.

include not only a method to store and reference data, but also include software to do simple data processing. Important characteristics of data storage retrieval systems include: data formats, storage and summary data techniques, management planning usage of data, and update capabilities. Usually large projects have their own storage retrieval system capabilities. Each project must give a great deal of attention to development of data formats for data needs to not only be stored but must be easily referenced for use in decision making.

Data can be stored in a number of ways. These include storing by way of mathematical or statistical formulae. Also, raw data can be stored, but requires large storage capabilities and these become quite expensive. It is important therefore, to consider what usage the data will be put to with regard to decision making in the ecosystem.

Figure 4 is an illustration of the typical data processing system. Processing data from such a system may include the process illustrated in Figure 5. Generally, storage retrieval systems require a good deal of specific data manipulation and therefore, necessary computer programs should exist for data editing. This procedure is illustrated in Figure 6.

Management decision making with regard to ecosystems is becoming dependent upon computer systems. One possibility for a computerized system network is illustrated in Figure 7. Each decision maker or ecosystem manager will have a computer terminal at his disposal to feed in simple data to a central computer. All the integral aspects of data processing will be conducted by the central computer and the required output will occur at the manager's request.

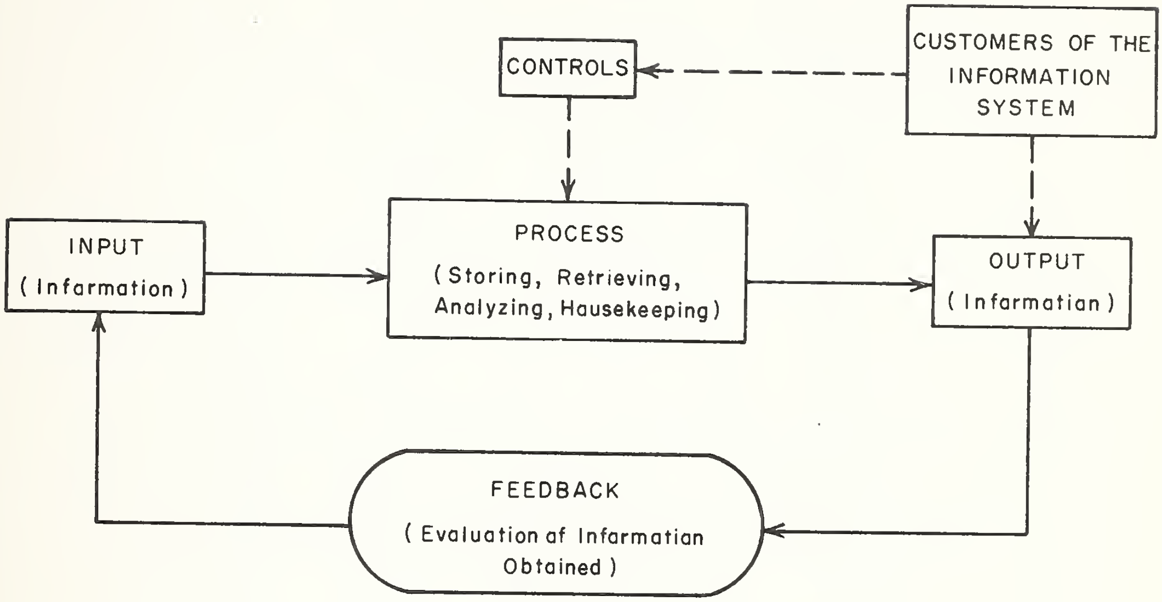


Figure 4. A schematic concept of an information system.

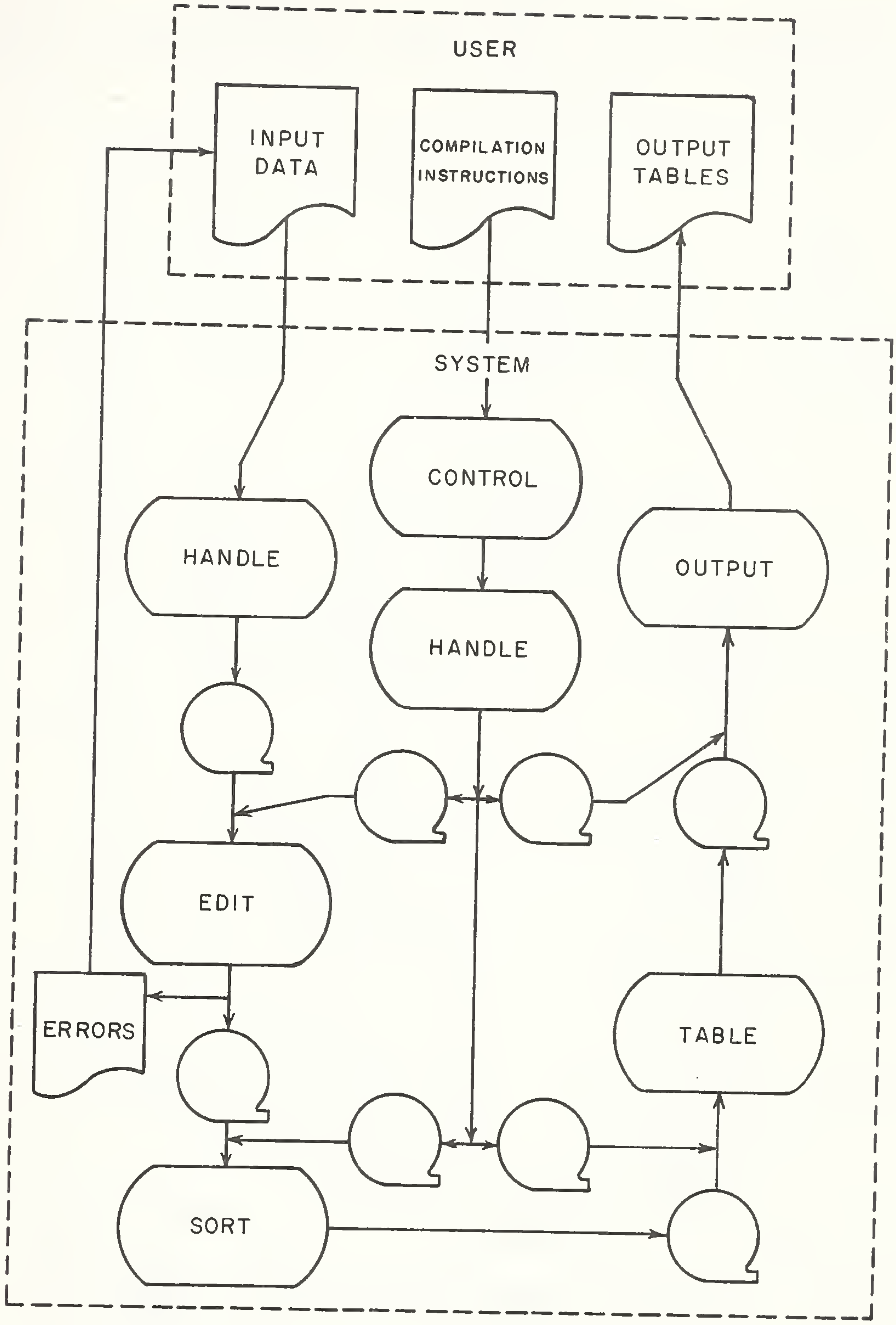


Figure 5. System configuration for processing a single sample.

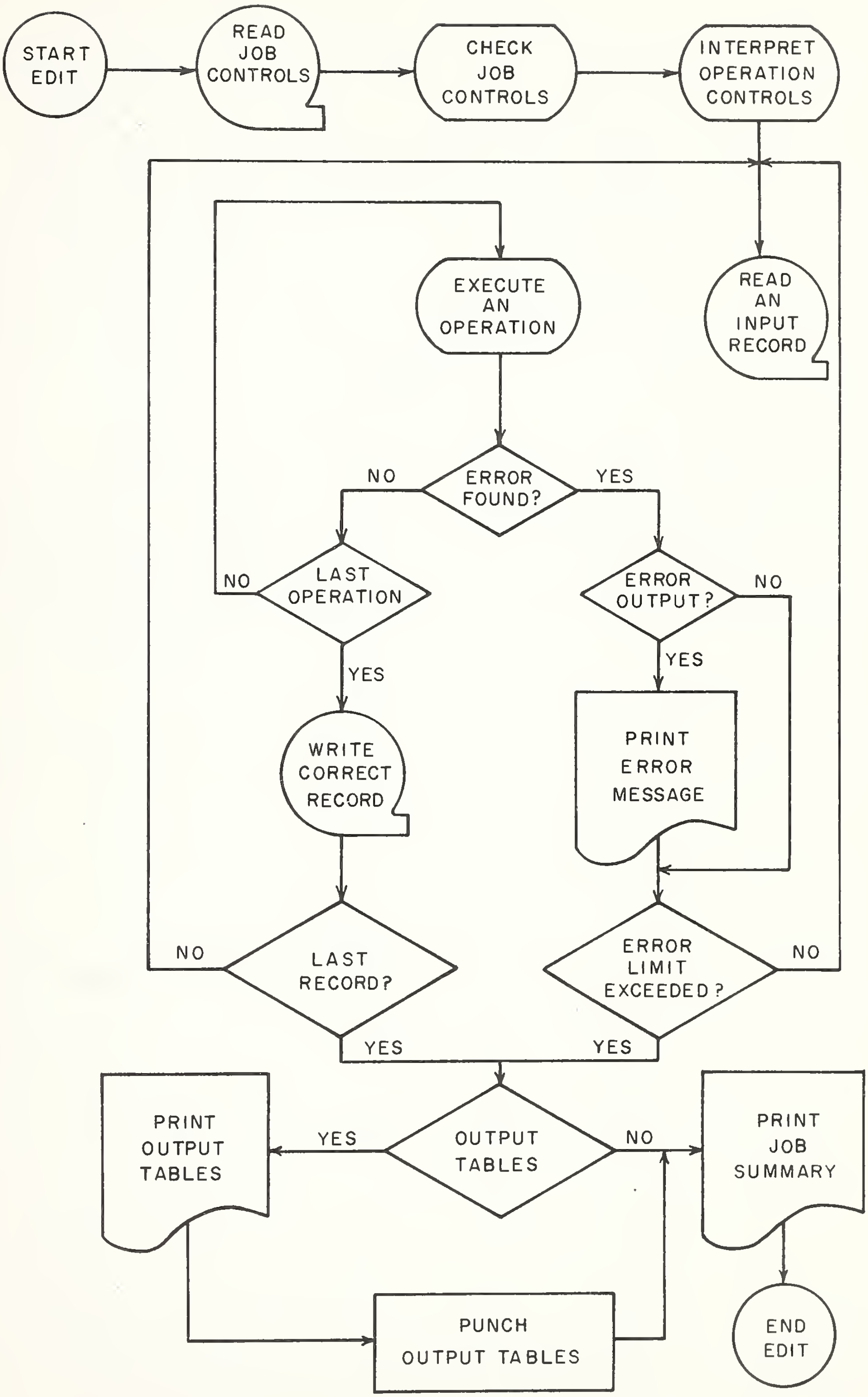


Figure 6. A generalized flow chart of EDIT.

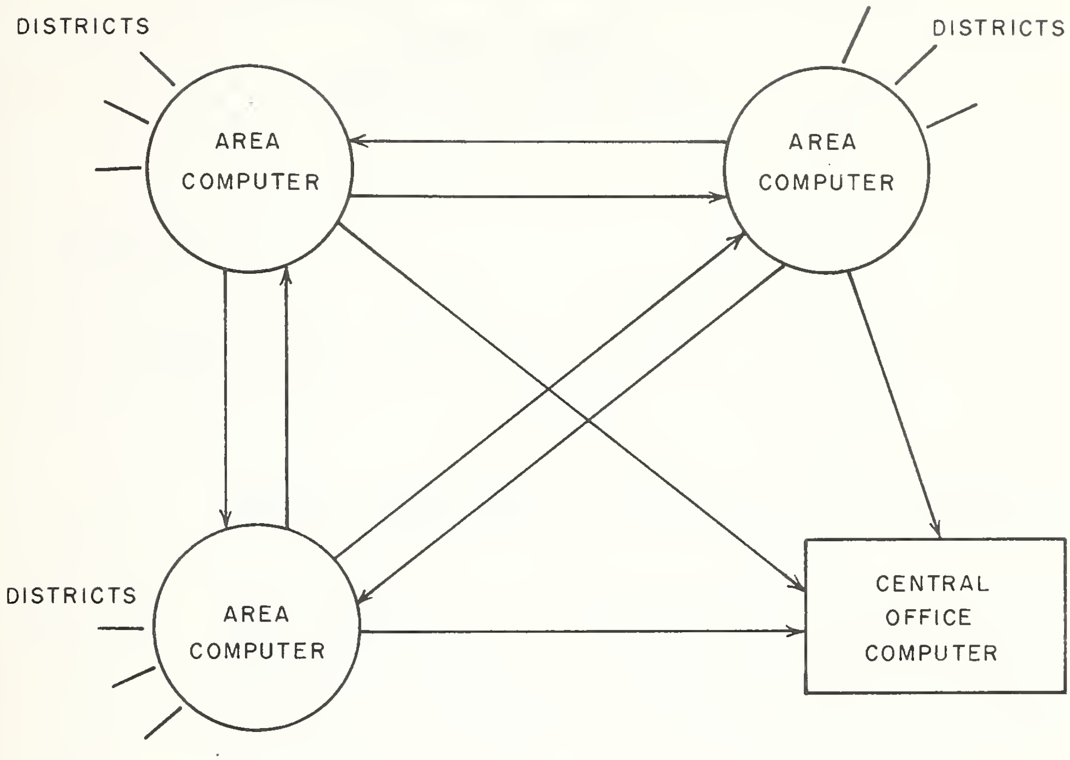


Figure 7. Computer-System network.

DECISION MAKING, SOCIAL CONFLICT, AND TECHNOLOGY

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I. INTRODUCTION

A. Technologies are complexes of standardized operations to obtain predetermined ends.

B. Technologies are social and political phenomena:

1. Technologies are social because they are developed, employed, diffused, constrained, and advanced by human beings acting in systems of social group affiliations.

2. Technologies are political because they are not socially neutral in impact; they promise to provide solutions to problems of some social groups while adding to the problems of others. The political question is: Whose problem is solved and whose definition of an acceptable solution? Technology is a major source of social conflict.

C. Purpose of this presentation:

1. To state some requirements for adequate assessment of technological policies, programs, and projects:

2. To outline one sociological approach to the problem of evaluating or assessing technological impacts on society.

II. CRITERIA FOR ASSESSMENT OF TECHNOLOGICAL POLICIES, PROGRAMS, AND PROJECTS

A. <u>The Criterion of Externality</u>--individuals and groups systematically over-invest resources in those activities in which significant costs are "externalized"--i.e., borne by groups other than the investors. Inadequate resources tend to be invested in those technologies which "externalize" significant benefits. Externalities can be the source of much social conflict and are social and political as well as economic. Good planning requires the mapping of externalized costs and benefits.

B. <u>The Criterion of Allocating Burdens of Uncertainty</u>--all projects have associated uncertainties. The question is who should pay the costs of such uncertainties. Rarely have developers and promoters had to establish "harmlessness" of their activities; opponents, more typically, have had to pay the costs of establishing "harmfulness." Good planning requires analysis as to which social groups are bearing the costs of uncertainty.

C. <u>The Criterion of Multi-Purpose Assessment</u>--social welfare is much too complex and multi-faceted to be measured by any single set of yardsticks. Planners possess assorted economic and other approaches to "welfare"; a sociological approach will be developed in this presentation. Good planning never relies on any single definition of the "public interest."

D. <u>The Criterion of Constituency Creation</u>--constituencies of the planner tend to involve themselves in activities at different times in the planning process. It is essential to know in advance which types of constituents will be asserting demands through time. Supportive and hostile constituents appear differentially according to time and incremental or non-incremental nature of the project impact. Good planning requires that new constituents can be accomodated as programs develop.

E. <u>The Criterion of Preserving Future Options</u>--planners should value highly those courses of action which retain the greatest possible latitudes for future action. Reversibility should be counted as a major benefit and irreversibility as a major cost. Good planning requires that irreversible commitments be made only in the context of maximum knowledge and socio-political support.

F. <u>The Criterion of Predicting Cumulative Effects of Scale</u>--Program impacts vary according to the amount of diffusion of the program. Planners should develop multipliers for certain time periods. Programs which may have most beneficial impacts at certain points on a diffusion curve, may have detrimental impacts at other points on the curve.

G. <u>The Criterion of Predicting Impacts of Converging Technologies</u>--multiple technological trends interact with each other to produce outcomes different than produced by any single one. Good planning requires that exchanges among projects and programs be evaluated.

III. A SOCIOLOGY OF CONFLICT APPROACH TO ASSESSMENT OF TECHNOLOGICAL PROJECTS, PROGRAMS, AND POLICIES

A. The above seven criteria, if made operationally useful, help the planner distinguish between "good" and "bad" planning effort. Every discipline can make a contribution to the analysis of the criteria in concrete "real world" settings. One sociological approach, emphasizing social conflict, follows.

B. Technology is a central source of social conflict.

C. Conflict can be organized into two polar types of conflict patterns or structures:

1. The Overlapping--associated with non-negotiable issues, with limited capacity to absorb change, and with high propensity to commit violence. Social Planners should assess projects with a view to reducing tendencies for this type of conflict pattern to develop.

2. The Cross-cutting--associated with greater capacity to absorb change and with low propensity for creating non-negotiable issues and violent behavior. Social planners should assess programs, policies, and projects with a view toward facilitating growth of cross-cutting conflict structures among social groups.

D. The planner can employ three kinds of data to map the structure of conflict in his unit of analysis:

1. Data about the perceptions of legitimacy among actors across cleavages;

2. Data about the perceptions of intensity among actors across cleavages;

3. Data about perceptions of mutual interdependence among actors across cleavages.

E. Cross-cutting cleavages are predicted by moderate or high levels of legitimacy, low levels of intensity, and beneficial (non-zero-sum) perceptions of interdependence. Overlapping cleavages are predicted by low levels of legitimacy, high levels of intensity, and detrimental (zero-sum) perceptions of interdependence.

IV. CONCLUSIONS

A. The analysis of conflict cleavages promises to be one method of approaching, in an operationally useful manner, the seven criteria of planning discussed in Section II.

1. Projects or programs which insert social conflicts on vectors overlapping other significant cleavages in the social fabric "externalize" significant social costs to society;

2. The question of coping with the "uncertainties" associated with any program or project can be at least partially approached by examining conflict patterns. A trend of growth or stagnation which contributes significantly to over-lapping conflict patterns should be carefully appraised as to whether it should be allowed to continue.

3. Multi-purpose assessment is served by provision of another yardstick for social welfare.

4. Insertion of conflicts on "overlapping" vectors reduce social options and are highly irreversible.

5. Diffusion of programs or projects means also the diffusion of social conflict patterns, a fact which provide one means of estimating cumulative effects of scale.

6. The conflict approach helps identify which constituents will be assertive of demands, provides means to predict the negotiability of the demands, and suggests means to keep issues negotiable.

7. Interacting technologies mean interacting conflict patterns. These sets of converging programs and projects which foster the convergence of conflict fronts on cross-cutting patterns are much to be preferred to those which converge on overlapping patterns.

B. Rationality cannot be thought of as a single-dimensioned concept. There are at least three types of rationality and to be "rational" in terms of one may mean being less than fully "rational" in terms of the others. Three kinds of rationality are:

1. Technical rationality--the rationality of pursuing one goal in isolation from other goals;

2. Economic rationality--the rationality of pursuing multiple goals which requires trade-offs among preferences;

3. Socio-Political rationality--the rationality of maintaining the viability of decision-structures per se. This is the rationality of keeping conflict cleavages cross-cut and issues among social groups negotiable.

C. In cases of inconsistency among the three types of rationality, technical rationality should be sacrificed to economic rationality, and both technical and economic rationality should be sacrificed to socio-political rationality.

Diagram 1

Freezing of the Planner

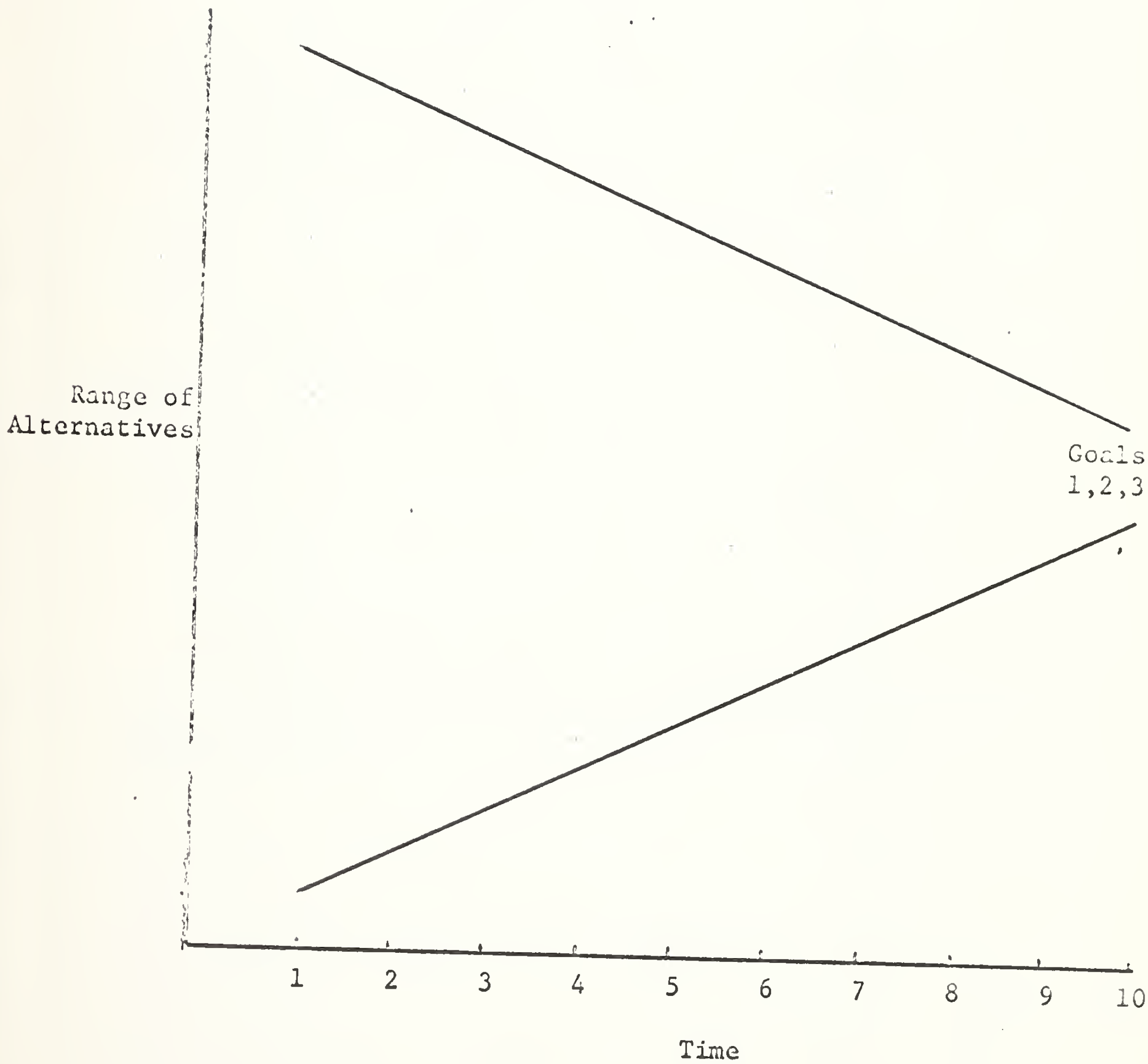
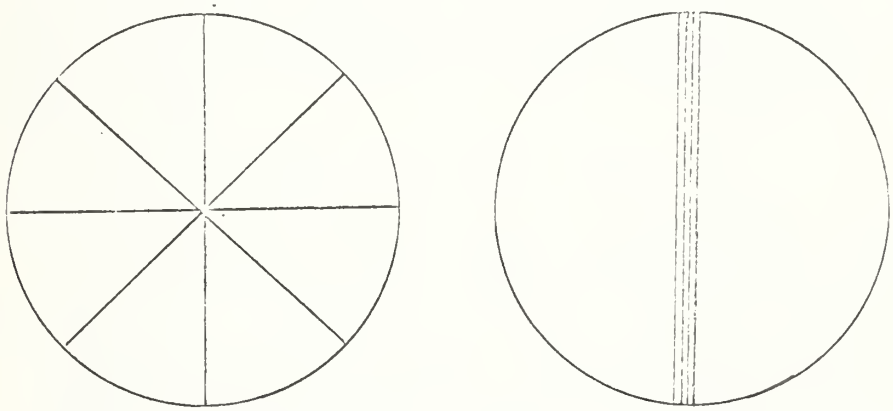


Diagram 2

Cleavage Structures



Cross Cutting　　　　Overlapping

ENVIRONMENTAL LAW AND CITIZEN PARTICIPATION IN RESOURCES DECISION MAKING

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I. The Conservation Movement at the turn of the Century (Roosevelt-Pinchot) was premised on the use of government to preserve, protect and punish despoilers of resources. This was the common theme that united the "liberals" and "conservatives" of that era, and continued to be a major thrust of the Movement to World War II.

II. A corollary was (1) the development of many conservation agencies and programs, and (2) the emphasis on professionalization most clearly evident in the development of Forestry Schools (Pinchot & Yale). Note the "technocratic" and elitist premises as evidenced in the Pinchot policy of rotation of assignments.

III. Citizen involvement and participation was minimal; the emphasis often was simply on legitimation. Contrast the "farmer committees" of the conservation payments program with the SCS Districts. The latter had little real authority as SCS employees took their orders from their fellow "federals" and ultimately from Washington. Cp. political roles.

IV. Two significant changes of the late '60s:

A. Growing disenchantment with many public programs (highways, urban renewal, water development, sustained yield cutting, etc.).

B. Demand for "maximum feasible participation;" a power ploy; but nevertheless significant, because it challenged the "public interest" orientation of the professional public servant. Often anti-intellectual; frequently revealing value conflicts and overspecialization.

V. In the cities, partly stimulated by the Poverty program, these changes resulted in the growth of new power centers: neighborhoods and the poor. It also initiated a rethinking of the goals and methods of urban programs and this task is by no means completed.

VI. With respect to conservation programs this lack of faith resulted in more active interest groups challenging government agencies and in many cases going to court to stop them from certain kinds of action. It also resulted in resources agencies re-examining their relationships to "the public" and talking more about citizen participation in planning. Often in fact because of the characteristics of agencies and agency programs "participation" tended to be just another word for legitimation, although in some cases it did result in broadening planning and action approaches and giving consideration to a wider range of factual interest inputs. Coordination with other agencies at State and Federal levels.

VII. But in many respects the development of environmental litigation and environmental law has been the most significant innovation. It has involved both the Courts and the Congress, and to a lesser extent the State legislatures. And it is very clear that this new emphasis rests to a large degree on a lack of confidence, if not on actual distrust, of the professional bureaucracy. It reflects, also, the fact that issues of environmental degradation and fears for the future have captured the imaginations of many people, politicians and publicists.

VIII. As recently as 15 years ago little thought would have been given to using the courts to protect the environment nor to seek positive legislation to control behavior of citizens with respect to natural resources.

A. Forest Service and control of cutting on private lands.

B. SCS Districts and land-use controls.

C. Stress on service, education, buying reform, stewardship.

IX. But now a growing public concern:

A. Urban with hostility to agency values and decisions; hostility to over-specialization; questioning of development and growth philosophy. Middle and Upper Class Activism; self-seeking.

B. Concern for population growth; quality of life.

C. Affluence which permits challenges to the establishment and establishment values.

D. A return to acceptance of "Social Control"--typical American simplistic belief that all that is needed is to pass a law--encouraged by lawyers in legislatures.

X. Resulting changes:

A. New Laws; e.g., Maryland siltation control; Iowa siltation; THE QUIET REVOLUTION IN LAND USE CONTROL--Federal Laws, too:

B. Litigation which I will discuss more fully in a minute.

C. New concepts among academics and government, most apparent in economic matters: WRC evaluation standards; stress on externalities; questioning of economic growth, GNP; Ecology and doomsayers.

XI. Focus on: Litigation and NEPA.

XII. Changes in court attitudes and procedures:

A. Standing to sue--a public, non-economic interest.

B. Discovery procedures.

XIII. Legal Doctrines and philosophies:

A. Common Property--fishing, water, air, landscape.

B. Externalities, spillover, nuisance.

C. Public Trust Doctrine--concern over bureaucratic bias, especially regarding "low visability" decisions, and lack of accountability.

XIV. NEPA and CEQ

A. Comments on legislative history and apparent intent.

B. The impact statements--a surprising sleeper.

1. Initial reaction: A PR job; agencies are competent.

2. Inability of CEQ to perform review function.

3. A "handle" for private suits vs. government.

4. Private interests become concerned over adequacy of 102 statements.

5. The issue of expert testimony.

6. The issue of balancing the equities--tradeoffs.

7. Coordination requirements; limitation on agency competence.

8. What about off-site or indirect impacts.

THE POLITICAL ACTION GAME

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The Political Action Game provides you with an opportunity to test your skill in the political system. You will play one of the roles involved in river basin planning. The success or failure of your role will depend upon your abilities as a pursuader, negotiater, and your facility at compromise. The game is designed to simulate the real political arena as closely as possible. You may make secret deals, break promises, apply economic pressure, buy votes, etc. However, if you do not fulfill your promises, you can expect to have sanctions applied against you by the other players. In order to point out the analogies between a political action game and real live politics, three lists of parallelisms have been provided to point out the actions the players have taken in the game and how these actions closely follow real life politics.

The Players

The Political Action Game has six players, each of which plays a role in the political system. The players are the Bureau of Engineers, the Wilderness Club, the Congressman, the Del Rio County Commission, the Del Rio Sportsman's Club, and the Del Rio Water Users Association.

The Bureau of Engineers is an old line traditional government agency that has built up a large cadre of political friends. The Bureau is primarily involved in the construction of navigation works, flood control projects, and hydro-electric plants. Because its activities are nationwide and have a major impact on local regions, it is heavily involved in the "pork barrel" aspects of politics. Because it has so many political friends throughout the nation, the Bureau is in a relatively invulnerable position in a political game.

The Wilderness Club works primarily for a river basin which will be retained in its natural condition. The Wilderness Club would like to see all or part of the Del Rio River Basin left in the state of a wild river. Because the Club's membership is small and its financial resources are limited, the Club has been unable to generate much political support for its position. Because the Club is just starting an up-hill battle to achieve some type of wilderness or wild river status for the Del Rio River Basin, it has very little political muscle.

The Congressman, like most congressmen, is in a relatively enviable position. The Congressman could be voted out of office during the next election, but for most incumbent congressmen, this is a relatively unlikely proposition. The Congressman has sufficient tenure in Congress that he has a large number of political friends in all phases of government. The Congressman is not in a position that he is forced to vote with any of the political roles involved in the Del Rio River Basin project. As a result, he can pick and choose the party or parties with which he wishes to become associated depending upon which party or position is able to give him the greatest amount of satisfaction.

The Del Rio County Commission is primarily interested in satisfying its constituents and gaining re-election. The Commission feels this re-election can best be gained by maintaining the prosperity of Del Rio County. The Commission is very undogmatic about how this prosperity is maintained, whether it be through the construction of dams, navigation projects, or through the development of a large recreation program which will bring in outside visitors. The County Commission is by no means as strong politically as the Bureau of Engineers or the Congressman. However, like most county commissions, the Commission is not entirely without political influence. The Commission members are well known and respected locally and it would take a great deal of effort to dislodge them from the County Commission.

The Del Rio Sportsman's Club is a newly formed organization which is devoted primarily to furthering the outdoor sports of hunting and fishing in the Del Rio River Basin. The Club members do have a tendency to lean towards the preservationists view of river basin development but at the same time they also work very diligently for the construction of access roads and campsites which can be used by hunters and fishermen. The Club is quite new and inexperienced in the political arena. Also, the Club has few members who have much political influence. As a result, the Club is at a severe disadvantage when competing in the political system. However, since the Club members are voters in local and national elections, the Club is not entirely without influence.

The Del Rio Water Users Association has been in existence since the early 1900s when many of the local farmers got together to construct and operate irrigation canals for their farms. Though the membership is not large, the Association is one of the key elements in the maintenance of a thriving agricultural economy in the lower reaches of the Del Rio river basin. Because the membership is made up largely of the old line families who are well known and respected in the region, the Association has a rather large amount of political influence. The Association has been working in the political system for almost seventy years, and the individual members are personal friends with many influential politicians at the local, state, and national level.

The Roles

The objective of the Political Action Game is to obtain a larger number of satisfaction units (S.U.) than any of the other players. The game is played for ten rounds and the player with the largest number of satisfaction units at the end of ten rounds is declared the winner. Satisfaction units are a common denominator for the rewards that all individuals involved in political action are attempting to attain. Satisfaction units mean different things to different players. For example, the Bureau of Engineers gains satisfaction if they are authorized to construct a dam or navigation project. The Wilderness Club attains satisfaction if a portion of the river basin is maintained in a wild river status. The Congressman gains satisfaction by achieving re-election. The County Commission attains satisfaction by maintaining a healthy economic climate, low unemployment in Del Rio County, and by gaining re-election. The Sportsman's Club gains satisfaction by improving and maintaining a large number of opportunities for hunting and fishing. The Water Users Association maintains its satis-

faction by maintaining a steady flow of high quality irrigation water and by improving its distribution system. While the physical developments that derive satisfaction vary from individual to individual, the ultimate end for each player is to achieve a high degree of satisfaction for himself.

As in real life, the game does not provide for everyone to start with the same degree of satisfaction. Obviously, if everyone is completely satisfied there is no need for political action. As in the real world, the "establishment" tends to have more satisfaction units than do the dissatisfied "radical" elements of society. Consequently, the establishment, Bureau of Engineers, begins with 60,000 satisfaction units and the establishment Congressman starts the game with 70,000 satisfaction units. The dissatisfied Del Rio Sportsman's Club starts the game with 2,000 satisfaction units and the even less satisfied Wilderness Club enters the game with zero satisfaction units. As in real life, there is also a middle-class element that is not completely disenchanted nor is it a true member of the establishment. The middle-class Del Rio County Commission and the Del Rio Water Users Association both start with 20,000 satisfaction units.

Playing the Political Action Game

Additions to or subtractions from the beginning satisfaction units will be determined by the voting combination that takes place during each round of play. Play is initiated by setting a stop watch or kitchen timer for a five-minute lobbying period. During this lobbying period the players may negotiate among themselves as to how each individual should vote during that round. At the end of the five-minute period, all lobbying must cease and a one-minute voting period is begun. During the voting period each player takes one of his ballots and places it face-down on the table. After the ballot is placed face-down it may not be changed. All ballots must remain on the table until each player has voted or until the end of the one-minute voting period. If a player has not voted by the end of the one-minute period, his vote will be counted as an "abstain" vote. When all six players have voted, or when the one-minute voting period is over, the ballots are turned face-up and counted.

The ballots are counted by adding the total of the numerical votes plus the number of yes and no votes. In most cases, a yes vote cancels out a no vote. Hence, if the ballots cast are: 2, 1, 2, 1, No and Yes, the yes and the no would cancel each other and the numerical votes would total seven for a total vote of seven. If the votes cast were 3, 1, 2, Yes, No, Yes; the numerical total would be six. One of the yes votes would cancel the no vote. Hence, the total vote would be one yes plus six. In all cases, an abstain ballot is counted as a zero. If two no votes are cast, there is no way a yes vote can cancel them out. Hence, if the two no votes are cast, the reward will also be a catastrophe, regardless of the number of yes or numerical votes also cast. Also, if there are no numerical votes cast and the numerical total is zero, such as if everyone voted to abstain, the reward would still be a catastrophe, regardless of the number of yes and no votes cast.

After the votes have been totaled, the players look to the board to find the road which holds their vote combination. That road is then fol-

lowed to the reward circle where the rewards are determined. The rewards are totaled on the score card and the next round of lobbying is begun. The winner is declared at the end of the tenth round.

Lobbying and other aspects of political action such as agreements, bribes, etc., may be carried out at any time except during the one-minute voting period. There can be no agreements entered into after voting takes place in the tenth round. The only adjustments that may be made in the satisfaction units of each player is to culminate any agreements made prior to the tenth round voting period.

Strategies

The players of the Political Action Game will find many of the same frustrations that are found in real life politics. For example, those who are out of power, the Wilderness Club and the Sportsman's Club, find themselves at a tremendous disadvantage when attempting to compete with the Bureau of Engineers and the Congressman. As a result, they will find that if they wish to win the game they need allies. Cooperation between players is necessary to guide the vote toward any particular road. At times this means that there is a necessity for cooperation between what would normally be considered traditional enemies, such as the Bureau of Engineers and the Wilderness Club. While the establishment starts out with a very distinct advantage, they will find that as the rest of the players become more skilled in political action they will be forced to cooperate with the radical elements if the establishment is to survive the game. As a general rule, you can say that no one player will be able to survive the game without cooperating with at least some of the other players. At the same time, any combination of four or five players should be able to control the outcome of the game if they fully utilize their skills at lobbying, making deals, etc.

Occasionally, it will be found that under-the-table payments will be made, promises will be broken, players will renege on payments. In effect, this means the game is being played as is real life. Players will find that when promises are broken, as in real life, they will have a difficult time in eliciting future cooperation from the players hurt. The result may be that the player who breaks promises will hurt himself more than he helps himself.

COMPUTER VARIATIONS ON A THEME BY MALTHUS

A Review of The Limits to Growth and its Critics

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The computers at M.I.T. have delivered themselves of the opinion that the world industrial order cannot make it beyond the twenty-first century. Either the carrying capacity of the world food system will be exhausted by then; or we shall all choke to death in a densely polluted environment; or, most likely, the world will simply run out of its stocks of non-renewable natural resources and the industrial system will consequently collapse.

Few books have evoked such critical response as this, The Limits to Growth. While fringe elements in the world of affairs (Robert C. Townsend) and in science (Paul Ehrlich) have applauded the work, proper science and economics have found it likely erroneous and certainly in exceptionally bad taste. If The Limits to Growth performed no other service, it has flushed out of hiding some of the peculiar attitudes and postures of their critics. More on this later.

The M.I.T. group probably finds as much solace in the bad reviews as in the good ones. For it is their favorite claim, and they never miss an opportunity to express it, that their "Systems Dynamics" produces "counter-intuitive results." It is alleged that only through this technique, backed by banks of large-scale computers, can one transcend ordinary common sense and achieve True Insight such as evinced in this book. Critical outrage merely confirms the suspicion that intuitions will necessarily be countered.

But in this particular case at least, the facts argue not so much the power of systems dynamics as the paucity of their critics' intuitions; for contrary to the claims of the M.I.T. group, the thesis of The Limits to Growth is not only not counter-intuitive, it is "intuitively obvious."

That economic growth must eventually cease was clear to John Robert Malthus, John Stuart Mill, and virtually the whole school of Classical economists. That it must stop within a century or so, and should stop sooner if any semblance of quality in human life is to prevail, has been argued by John Maynard Keynes; Kenneth Boulding; in the National Academy of Science book Resources and Man; by Ezra J. Mishan; and, perhaps most cogently, by Paul C. Barkley and myself.

But it is true that none of these "precursors" to The Limits to Growth have succeeded in provoking the intuitions of the naive nearly so well. Both the reason why this is so, and the reason why intelligent people quarrel with the obvious even after it has been pointed out, lies in the particular art form chosen for this book. The authors have employed the love of numbers, the esoterica of mathematics, the aesthetics

of the printout sheet, in a word, the computer mystique to make a statement to which even the most obtuse must respond. They have used the games and fantasies of proper science against itself.

In employing this art form, the authors have simultaneously created a Nabokovian complex of dead ends, red herrings, and false starts both to confuse and entrap their opposition and to camouflage the essential obviousness of their thesis. Their critics bemoan the lack of hard "data"; they complain that there exist no well-established "functions" to justify the time paths generated; the role of "technology" is not properly appreciated; and so on. The truth, as the authors clearly perceive, is that it doesn't matter.

Both the grounds of this assertion and the ingredients of a modern American dilemma are contained in the 1972 Joint Economic Report of the Joint Economic Committee of the Congress. An unusually large proportion of this report is concerned with the specter of resource depletion, pollution of the environment, the quality of life. These problems are considered of grave concern. Most of the report is more business-like. Unemployment is high; in order to reduce unemployment the economy must grow faster. The potential growth rate of the economy -- that rate of growth necessary to keep unemployment to 4 percent -- is calculated. A graph shows how the economy has tended to miss this target in the past three years. The balance of the discussion concerns various monetary and fiscal means of getting back on the 4 percent growth target. In this respect the resource-environmental quality parts and economic growth parts are connected "by nothing more substantial than the binding." Indeed, the desirability of economic growth itself is not promoted: the formal argument is simply that we must grow in order to work.

The potential rate of growth, so defined, in this report is about 4 percent per annum in constant, 1971 dollars. (During the period 1965-1971 it was slightly higher -- 4.3 percent.) At this rate (which is also the rate used in most economic forecasts) the U.S. economy will double roughly every 18 years. Table 1 presents an extrapolation of this growth rate in constant 1971 dollars.

	Trillions (000,000,000,000)
1971	1
1989	2
2007	4
2025	8
2043	16
2061	32
2079	64
2097	128

Trillions are even more unimaginable than billions. In order to put this series into focus, it may help to realize that with a 2097 U.S. population of twice the present number and with a $128 trillion economy, the average family income would be in excess of $600,000 per year in terms of 1972 purchasing power.

It seems "obvious" that such a level of production and consumption cannot be attained, much less that if attained, sustained. Indeed, as will subsequently be shown, there are reasons to believe that the present level of income is not sustainable. Be that as it may, the nature of compound growth makes it virtually impossible to argue in favor of perpetual growth -- the dice are always loaded against the proponents of perpetual growth, in favor of the opponents.

The reason is shown in Figure 1. Given any growth curve G and any limit L, the rate at which the limit is approached accelerates with time. Once the base becomes sufficiently large, the increase in quantity necessary to maintain a constant rate of growth per unit of time approaches infinity. Thus, once a sufficient base is established, quarrels over sustainable limits involving enormous differences of quantity reduce to quibbles over a few decades more or less. Malthus could easily have been wrong for 150 years and right in 18 more.

If it can be agreed that perpetual growth is a myth, the discussion can turn to more substantive and controversial issues concerning the level, timing, and nature of The Limits to Growth.

Figure 2 defines the status controversaie. There exists a path of income, "L", gradually increasing with time as technology progresses which can be sustained. This path defines the sustainable limits to growth. Actual income, Y, can grow beyond L as shown at the point A. But if it does, non-renewable resources will be exhausted at more than the sustainable rate. Therefore, as income grows beyond this point, the sustainable level of income falls along the path L'. Eventually, actual income will grow beyond its base as at point B. Income will begin to fall as more and more resources are depleted, finally to converge with L'at a Neanderthal level of sustainable income as shown by point C.

In order to avoid the deluge, it is necessary to bring actual income, Y, into convergence with sustainable income, L. There are two alternative policies.

The free market philosophy holds that the best policy is simply to let the system grow as it will. As the point A is approached, resource prices will rise. The cost of commodities will rise relative to the benefits of leisure. Scarce resources will be conserved, people will consume less and play more, and the system will naturally converge to the sustainable path, L.

Interventionists, on the other hand, believe that economic growth is as much a contrived as a natural phenomena, and they fear that it is precisely in this area of estimating the sustainable path of growth that the market system is prone to failure. The inherent bias of the market

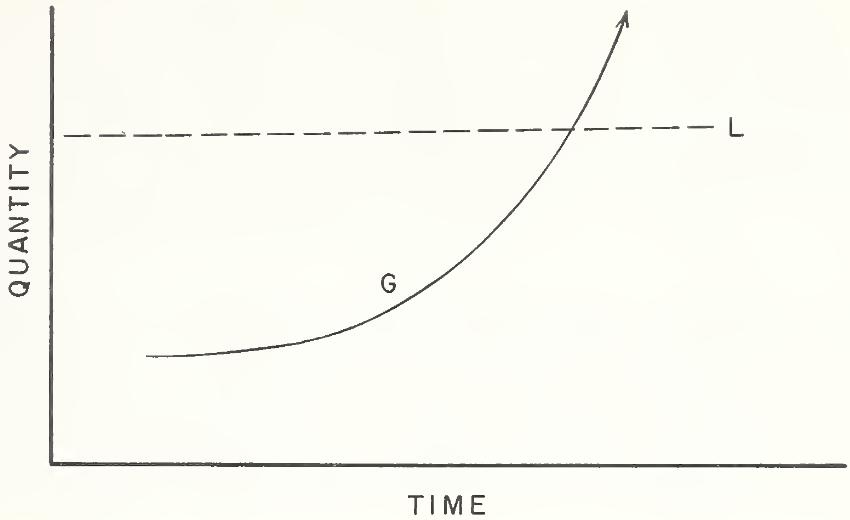

Figure 1.

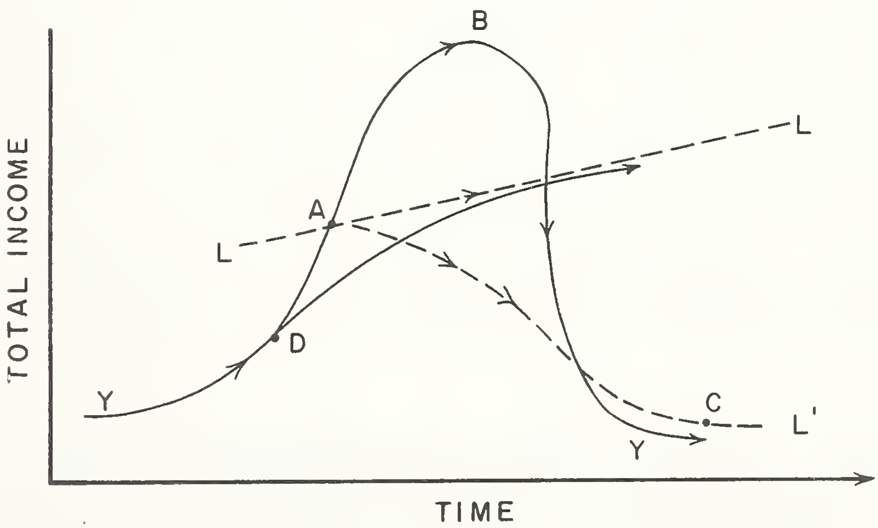

Figure 2.

is toward present, as opposed to future, consumption. The present value of a resource 50 years from now is pitiful. Further, the market creates great opportunities for certain individuals to collect the benefits of resource use, letting others pay the cost. In this case the opportunity is irresistible, for the present generation can collect the benefits and future generations (who have neither money nor votes) will pay the costs. Therefore, interventionists believe in deliberate policies to decelerate economic growth toward convergence with L.

The manner of convergence also differs between the two philosophies. Interventionists do not believe in an abrupt transition from rapid to low growth as at point A. Instead, they want to begin the process earlier as at point D in order to give society time to accommodate to the radically different life style implied by a low-growth economy. Certain preconditions must be met before convergence: policies for meeting problems of armaments, international trade, unemployment, poverty, leisure, to name but a few, must be instituted.

Controversies between these two approaches are very real -- neither side pretends to have simple answers. They agree on only one thing: that perpetual growth is not a realistic philosophy and people must begin preparing to accept the inevitable.

Which people? This generation? or the next? or those of the twenty-third century? The authors have made extensive computer explorations of this question. The most striking evidence, however, is contained in a simple table on mineral resources.

The authors take U.S. Bureau of Mines' estimates of world reserves of major resources. They provide estimates of the run-out times of these resources if consumption remains at current levels. This "static index" is, for example, 2,300 years for coal, 26 years for lead, and 11 years for gold. Then they calculated run-out times given current rates of increase in use of these resources. These are: coal-111 years, lead-21 years, and gold-9 years. Then they assume that actually there are five times the reserves of all resources as estimated. Under this assumption the run-out time goes to 150 years for coal, 64 years for lead, and 29 years for gold. From the point of view of estimating the point D, the static reserve index is perhaps most striking. At current levels of production with no growth in rates of use, only seven of the 19 very important resources listed in this table will last a century. It is in these rather obvious, pencil and paper kind of calculations rather than in the elaborate facade of "systems dynamics" that the compelling power of this little book lies.

Critics of The Limits to Growth have concentrated their fire on the implicit neglect of "technological progress" in this work. One critic observed, in a phrase obviously intended to be the coup de grace, in this analysis "technology grows linearly, while everything else grows exponentially." The statmenet is patently erroneous. All the projections of resource depletion, for example, are based on U.S. Bureau of Mines' estimates of future use rates which explicitly include technological progress. Other projections, such as industrial production, include

rising factor productivity as an implicit, historical phenomena insofar as it pertains. What is actually missing -- and in this reader's opinion, it is high time that it should be missing -- is the quasi-religious belief that as problems arise a mysterious technology, disembodied from the real world of matter and energy, will simultaneously arise to make the problems go away.

Technologists are imaginative fellows, and they can always imagine a solution to anything -- if both direct and indirect costs are conveniently forgotten. Endless repetition of their visions has inspired a state of mind wherein simple incantations of words like technological progress automatically induce people to go back to sleep. From now on, let us hope, we will not discuss "technological progress" in the abstract but specific technologies which are in the range of current knowledge, with estimates of their own matter and energy requirements, and in light of their environmental cost. If breeder reactors are to save us from the energy crisis, let's make sure _first_ that radioactive emissions and wastes (not to speak of the material requirements of breeders and related power and transmission facilities) are not going to create more problems than they solve. If breeders are found wanting and fusion reaction is to be the salvation technology, it would be convenient to know: first, if a fusion reactor is theoretically possible; and, second, if possible, whether engineering technology can actually make one. Certainly one of the more insane proclivities of modern man is to rush down irrevocable paths of behavior on the off-chance that simple ingenuity, whether in "planning" or in "technology" will save him. There _are_ insolvable problems, certain ends cannot be reached, the most important problems are solved not by better means but by an "agonizing reappraisal" of irrational ends which have created insolvable problems.

The Limits to Growth is a dramatic contribution to a growing literature reassessing the relations between economic growth and technological progress. This literature is not directed "against" technological progress except by the simple minded, nor does it discount technology as a major factor in economic growth. It simply affirms what should have been obvious at the start: technology does not perform miracles; while it is a powerful means of transforming inputs into outputs, inputs are still necessary; there are no free goods.

Even some economists have become entrapped in the free good mythology. Not long ago it was believed that as much as one-half of the increase in output could be attributed to increased factor productivity, the other half due to increased factor inputs. A classic study of the growth of the U.S. economy over the period 1945-1965 attributes most of this high productivity to statistical errors in measuring input; for example, not counting inputs to training and education of "human capital". The study concludes that over the period 1945-1965". . . the rate of growth of input explains 96.7 percent of the rate of growth of output; change in total factor productivity explains the rest."

Nor do statistics on the rates of use of mineral resources confirm the free good mythology. Perusal of the U.S. Bureau of Mines' _Mineral_

Facts and Problems leads to the following general conclusions: "technological progress: has increased the demand for resources as much as their supply. Known reserves are not increasing as fast as demand. Nor are costs of mining low-grade ores falling. The rate of growth of use for mineral resources averages to the same as the rate of growth of GNP, and forecasts of future rates of use of these resources, including foreseeable technological changes, reach the same result. In light of these facts, the following statement acquires a particular poignancy. "In the last 30 years the United States has consumed more minerals than the entire world for all time before. Based on the forecasts for the year 2,000 the total constant dollar value of demand for minerals in the nation is expected to increase from three to five times the present level."

Lastly, it is often thought that the drift to a services economy -- finance, insurance, police, the law, teachers, T.V. repair, and the like -- will create a less resource-using economy. But just as "a life of predation implies something to prey upon," a services economy implies something to serve. What is served is other people and their appurtenances. These are cities, mainly, and what keeps cities going. It is not perverse to think that a highly industrialized urban economy with its related transportation, communication, construction, and waste disposal systems will draw on more, and more scarce, resources than its more primitive counterparts; and the facts seem to bear this out.

In sum, the difference between an American and an Indian standard of living is not so much the efficiency of obtaining more output per unit of input as it is the technological capacity of the American to employ vastly greater inputs per unit of time. This is good for present, if not future, Americans and bad for present, if not future, Indians.

I conclude that not only have the authors provided a good case for their thesis but that this thesis accords both with common sense and independent evidence. Ironically, it is perhaps the strength of their thesis rather than its weakness that has promoted the exceptionally venomous and sarcastic attacks on the authors of this book, as epitomized by Robert Gillette's review in the American Academy for the Advancement of Science magazine, Science.

> Featured in the cast of Limits to Growth are an earnest young systems analyst, his biophysicist wife, their computer, and a gaggle of youthful colleagues at M.I.T. There's also a globe-trotting industrialist-cum environmentalist named Aurelio Peccei and his enigmatic Club of Rome, plus a galaxy of inadvertent supporting stars caught by the TV cameras in cameo appearances.
>
> Never mind that hardly a reputable economist can be found who thinks these projections amount to more than a fascinating exercise in model-making. Never mind that not a shred of this has yet been exposed to critical review in a scientific journal. There's not enough time to fiddle with stodgy publications and their interminable lead times. . . . The amenities of science aside, the world must be alerted, authorities must act.

Does Meadows get his message across? You bet he does. It's all done with a readable little book for laymen that may very well prove as popular as Linus Pauling's recent treatise on vitamin C.

Their feelings of technological omnipotence threatened by The Limits to Growth but lacking any substantial refutation, critics such as Gillette have deflected their aggressions, like Lorenz's stickleback fish, away from a powerful thesis to the hapless authors.

But Gillette's attack is much more important than a simple exercise in invective. It is based on a certain methodological view of science which argues for the step-by-step accretion of verified truths as determined by reputable scientists and publication in their journals. There exists an alternative theory of scientific methodology which holds that the origin of hypothesis is a matter of utter indifference; that the more bold the hypothesis, the better. And that science proceeds through attempts to refute bold hypotheses. Certainly, in this latter interpretation the authors of The Limits to Growth stand in the finest tradition of science.

POLITICS OF ECOSYSTEM MANAGEMENT

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The politics of ecosystem management relates to the establishment of the criteria that govern decision-making on actions taken in public ecosystem management. The physical and biological knowledge involved in such decisions is scientific and professional; and the criteria determined by politics permits, within limits, such knowledge to have its role. For example, the methods of harvesting timber are largely established by professional standards, but the criteria which determine which method will be used are determined by politics involving public conceptions of the values of a forest. Similarly, the role that professional economic analysis has in ecosystem management is determined by the political process. On the other hand, the social system provides the social environment within which ecosystem management must cope. Finally, the social system interconnects with the political system in the determination of the criteria which govern public ecosystem management. So much for establishing the general role of politics in public ecosystem management.

The political system in the United States which establishes the official policies (i.e. the criteria that govern a public decision to take, or not to take, an action) includes the following political actors: citizen-voter; political parties; interest groups and their leaders; influential persons; and official policy-makers--legislative, executive and judicial. The political power of any of these actors in a given situation can be gaged by the relative deference paid to their policy positions; or, stated another way, by the extent their views can be ignored without adverse consequences. On the other hand, political legitimacy of a policy decision, in terms both of legality and political acceptance, turns to a substantial extent upon meticulous maintenance of what are accepted by political actors as proper procedures for official policy-makers in making a policy decision.

Competition over policy issues, as well as cooperation involving coalition of interests in majority building, is the characteristic activity of political actors. With the input also of professional advice, policy alternatives emerge from this activity which finally mature into a policy decision. In this context, professional ecological and economic knowledge is important in appraising the feasibility of alternative policies. Decision among them, however, will turn on the social values they represent to official policy makers.

The output of the political system embodying policy decisions includes: authorizing legislation, appropriation legislation, legislative history; judicial decisions; executive regulations; formal and informal executive policy statements plus the decisional criteria that only become evident upon examination of a series of action decisions. In making an action decision the public administrator must take into account the policy criteria from all these sources that are relevent to any action he proposes to take.

The enactment of the Land and Water Conservation Fund Act in the 1960's well illustrates the operation of our political system in making a policy decision that establishes basic criteria affecting a wide sphere of ecosystem management. This is the Act authorizing the setting aside of monies into a special fund: to purchase needed recreational land and water areas at the Federal level, principally by the Forest Service and the National Park Service; and to provide 50 percent grants to states and local governments largely for their purchase of needed recreational land and water areas. Recreation lands in the terms of the Act include areas providing open space and preservation of scenic beauty and other natural values as well as areas for swimming, picnicing, tennis, horseback riding, etc.

The process of enactment of the Act started from a general value premise of a political leader and official policy-maker, former Secretary of the Interior, Stewart L. Udall. The process continued with development of some key implementing ideas, testing of these ideas through responses to public speeches, continual reshaping and enlarging the original conception to cope with the political power of other participants in the decision-making process (e.g. the Secretary of Agriculture). Thus, "consensus" or a "majority" was built that led to enactment some four years after initial conception of the Act.

Initiation of the process of policy development or change can begin, of course, with any political actor. The initiation in 1956 by the Wilderness Society of the general legislative ideas embodied eventually in the Wilderness Act of 1964 is an example of a policy change initiated by an interest group. Other types of initiatives could be cited. Whatever the origin of a policy idea, the political legitimation process appropriate for it must be carried out if it is to become operative as public policy.

What, in general, can be said about the past, present and possible futures of the politics - or more particularly, the basic controlling values - impinging upon ecological management? As regards the past, the Traditional Conservation Movement, initially led by Gifford Pinchot, established the basic value premises, based upon a philosophy of utilitarianism, in support of policies of "sustained yield" of renewable resources and "wise use" of non-renewable resources. These policies dominated ecological management, outside the realm of the National Park Service, until the 1960's.

John Muir, the founder in 1892 of the Sierra Club, in his fights for National Parks well into this century; Aldo Leopold and Bob Marshall within the Forest Service and Howard Zahnhizer and others outside the Service, through the Wilderness Society, in fostering establishment of wilderness areas--all of these leaders strongly asserted value premises as a basis for policy development in opposition to Pinchot's conception of utilitarianism. Also, since publication in the middle of the last century of "Man and Nature" by George Perkins Marsh, the normative value of ecological insights, as well as their scientific validity, have been asserted by ecologists and others in opposition to the "developmentalism" with which the Traditional Conservation Movement tried to make peace. Some substantial

practical results materialized from all of these efforts prior to 1960 (e.g. establishment of the National Park Service in 1916). But the basic ideas of this opposition had not yet pervasively penetrated traditional conservation ideology.

The New Conservation, or the Environmental Movement that began in the early 1960's, initially asserted not utilitarian values, but the value of "environmental quality," conceived in terms largely of esthetic values, as of over riding importance. More recently, with publication of various visions of man's possible calamitous effects upon the liveability of the earth, for man as well as other living things, "environmental security" has become a major value concern of the current Environmental Movement. Not esthetics, but security of life itself, is the main value, as I see it, behind such policy proposals as "no growth in population," banning of DDT, control of mercury pollution or - in part - the withdrawal of Federal financial support of the SST.

Extrapolating into the future one might generalize and say that the basic value impinging upon ecological management will be, or at least should be, the achievement and maintenance of a sustainable relationship of man in nature. Ecological insights, both normative and positive, superimposed upon the utilitarian doctrines of multiple use and sustained yield, would provide the necessary intellectual underpinning and policy guidelines.

As is true now, a sustainable relationship of man in nature will involve concern at the micro-geographic level with maintaining natural beauty and natural ecological systems versus continuing demands for material goods and services that destroy such values. But, more than now, this concern for a sustainable relation of man in nature, as indicated by the UN Stockholm Conference in June 1972, will focus upon the macro-geographic level, concern with man's effects upon a nation as a whole, large regions of the earth, and the earth as a whole. Clearly, to make such a sustainable relationship operational at the macro-level, one must postulate achievement not too many decades hence of "no growth in population" and "no growth in per capita national income." The marked decline of the birthrate in the United States in recent years indicates that around the turn of the century we could achieve "no growth in population," but no dent has yet been made in the official U.S. policy of four percent growth, compounded annually, in gross national product. Also no substantial amount of economic research has yet been focused upon the implications of changing to a policy of "no growth in per capita national income" from the points of view of maintaining economic stability at "full employment" or of achieving equitable distribution of income under "no growth" conditions.

Hopefully, with the increasing material affluence projected for the next several decades, poverty problems will be solved and a decline in the marginal utility of material goods will occur -- without undue government regulation -- by an early decade of the next century, at least in this country. The marginal utility of the third automobile or the third TV is much less than the second. With higher incomes, the marginal utility of leisure service functions will increase. To the extent these tendencies

operate in our society, they will work in the direction of "no growth in per capital national income" and of providing increased leisure time. This could mean more people more often visiting National Forests for all types of outdoor recreation experiences and less growth in the demand for commercial forest products.

What does all this mean for the U.S. Forest Service? Fundamentally, this means that:

-- it must reexamine the premises of its present ecosystem management in the light of what is being said in the current Environmental Movement and of possible future economic trends.

-- it should obtain establishment of policies to guide its ecosystem management that include the new environmental premises and accommodate them to the continuing relevance of its traditional policies (e.g. sustained-yield forestry; and

-- it should reexamine its whole administrative and policy leadership roles, particularly its relations with interest groups, so as to assure its own institutional viability in the years ahead.

Conceivably, this latter reexamination could call into question its present departmental location within the structure of the Federal government and its cherished tradition of the Chief Forester being a civil servant. If a Department of Natural Resources is established, with the Forest Service included and along the lines proposed by President Nixon, then it seems to me the logic of maintaining the Chief Forester as a civil servant is strengthened. It could also help forestall continued loss of jurisdiction over its lands.